A128 945 SYSTEM DESIGN PLAN FOR A DCS (DEFENSE COMMUNICATIONS SYSTEM) DATA TRANSMISSION NETWORK(U) DEFENSE COMMUNICATIONS ENGINEERING CENTER RESTON VA 1/1

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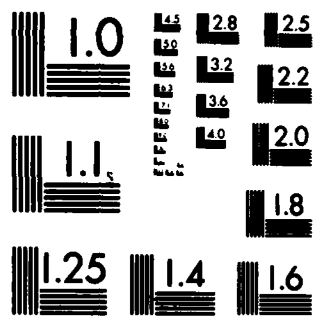

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TECHNICAL REPORT NO. 8 - 81

SYSTEM DESIGN PLAN FOR A DCS DATA TRANSMISSION NETWORK

JULY 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

To accommodate changes in digital data requirements and to capitalize on the evolution of the DCS to digital operation, a Data Transmission Network (DTN) is being planned to achieve a more efficient and effective transmission of data. This report documents the system engineering required for the DTN by establishing the transmission equipment configurations to be employed, defines user and subsystem interfaces, and describes circuit engineering criteria.

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JULY 1981

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FOREWORD

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EXECUTIVE SUMMARY

During the 1980-1990 time frame, the Defense Communications System (DCS) will continue to transition from an analog transmission and switching system to a digital-based system. This transition is driven by the need for transmission security and the economic and operational benefits of new digital processing technology. Associated with the transition to digital transmission, a Data Transmission Network (DTN) is being planned for the DCS to achieve a more efficient and effective multiplexing and transmission of existing, planned, and projected digital data circuits.

The DTN as a worldwide network is to be structured to provide full duplex, point-to-point, and multi-point digital data transmission services for a variety of applications at data transmission rates that initially range from less than 35 b/s to 64 kb/s. Typical applications range from on-off control signals for keying HF transmitters to providing Defense Data Network (DDN) Interswitch Trunks (IST's). Future applications of the DTN are expected to satisfy user requirements for higher data rates.

The implementation of the DTN will generally be phased to the implementation of terrestrial and satellite digital transmission facilities throughout the DCS, and will be structured to satisfy new digital data transmission service requirements as well as those presently being satisfied by Voice Frequency (VF) channel modems, FDM group modems, and Voice Frequency Carrier Telegraph (VFCT) networks. The DTN will be a synchronous network and its implementation must coincide with the implementation of the DCS network synchronization subsystem under the Timing and Synchronization Program.

The objective of this report is to document the system engineering for the DTN and to provide the technical basis for its implementation. To that end, the report describes the network design and the data transmission capability to be provided. In addition the report addresses user to user data transmission performance, digital signal interfaces, network synchronization, transmission equipment configurations, and network engineering considerations.

The report describes a preliminary worldwide network design which was also used to prepare the DCS 1983 Five Year Program (FYP). This worldwide network includes approximately 5000 circuits identified in the DCA and Military Satellite Office (MSO) data bases. The circuit requirements are accommodated by approximately 800 data trunk groups routed over Government-owned and leased transmission facilities. Further, the report addresses a proposed initial implementation that includes 14 data trunk groups accommodating 156 data circuits that will demonstrate network operation using typical terrestrial and satellite transmission equipment configurations.

The report presents the standard data transmission capabilities that will be provided by delineating the transmission rates, signal electrical interface parameters, and timing modes. The standard rates provided by the DTN will be the 75×2^N rates from 75 b/s to 19,200 b/s and the 8000N rates of 8, 16, 32, 56, 64, 128, 256, 512, and 1,544 kb/s. In addition, many nonstandard,

low-speed rates will also be included because of the large number of older terminal equipments still in use that require these rates. The electrical interfaces characteristics to be accommodated are Non-Return to Zero (NRZ) and Conditioned Diphase (CD). The timing modes accommodated will be synchronous, asynchronous, and isochronous. The operation of the network and its performance will be strongly dependent on maintaining standard digital interface characteristics and network synchronization. The electrical interface and digital signal quality characteristics are defined in detail. Also discussed are the network synchronization concept and the equipment clock configurations needed for proper system operation.

The transmission facilities that will be used to provide the telecommunications capability for the DTN include the terrestrial and satellite digital DCS, leased digital facilities, and Government-owned and leased analog facilities. The report addresses typical interface and clock arrangements for the multiplex, encryption, and radio equipments used to implement these transmission facilities.

Engineering considerations relative to implementing the DTN have also been included. Since the DTN is a worldwide synchronous network, its design must be considered from user-to-user and its implementation must be coordinated on a worldwide basis. To that end, the implementation of a modified version of the initial implementation presented in this report is presently being planned by a DTN Working Group. The Working Group is chaired by DCA and has representatives of the DCA Field activities and Mildeps.

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I. INTRODUCTION

During the 1980-1990 time frame, the Defense Communications System (DCS) will continue to transition from a system based on analog transmission and switching facilities to one based on digital technology. This transition, which is driven by the need for security and the economic and operational benefits of digital processing, will be accompanied by the growth and restructuring of the digital data transmission requirements to be satisfied by the DCS. To accommodate these changes in digital data transmission requirements and to capitalize on the evolution of the DCS to digital operation, a Data Transmission Network (DTN) is being planned. The DTN should achieve a more efficient and effective multiplexing and transmission of existing, planned, and projected digital data circuits.

It is expected that the DTN will evolve as a worldwide network of transmission facilities structured to provide full duplex, point-to-point, and multipoint digital data circuits for a variety of applications. The data transmission capability will be provided at transmission rates that initially range from less than 35 b/s to 64 kb/s. Future applications of the DTN are expected to satisfy user requirements for data rates up to 1.544 Mb/s and beyond. The implementation of this network will generally be phased to the deployment of digital transmission facilities throughout the DCS, and will be structured to accommodate new digital data transmission requirements as well as those presently satisfied by Voice Frequency (VF) modems and Voice Frequency Carrier Telegraph (VFCT) networks. Further, data circuits can be extended over present analog FDM facilities using VF or group data modems. In addition to the availability of terrestrial and satellite digital transmission facilities, the implementation of the DTN also requires the coordinated implementation of the Low Speed Time Division Multiplexer (LSTDM), the DCS network synchronization subsystem, and ancillary equipments (e.g., line drivers, VF Modems, Group Modems, and test equipment). Note that the LSTDM has recently been assigned the nomenclature AN/FCC-100 (V), and is currently scheduled for production by early 1983.

II. OBJECTIVE

The objective of this report is to document the system engineering required for a Data Transmission Network (DTN) in the DCS and to provide the technical basis for an orderly and effective implementation. This report describes the transmission equipment configurations employed, defines user and subsystem interfaces, and describes circuit engineering criteria. These will provide system level guidance for subsequent implementation engineering of the network and the development of operational management practices and procedures. The report provides the technical detail to support the implementation of the DTN that is contained in the current DCS Five Year Program (FYP).

This report is organized to present the system design of a DTN in the following sequence:

- A generalized description based on the DCA FYP 83.
- A description of the digital data transmission and user interface characteristics that can be provided.
- User-to-user digital data circuit performance objectives that have been established for this transmission capability.
- A description of an initial implementation of DTN trunks which were configured to demonstrate the various capabilities of the DTN.
- A detailed description of the transmission equipment that comprises the DTN.
- A definition of the DCS network synchronization subsystem that is necessary to support the DTN.
- Network implementation engineering considerations.

A follow-on supplemental document is planned that will address transmission and crypto equipment interfaces, and network performance. This report should be available by early 1983.

III. DTN DESCRIPTION

A functional representation of a Data Transmission Network (DTN) is presented in Figure 1. All data users have Data Terminal Equipment (DTE) which is the originator (source) of data, and the receiver (sink) of data. The DTE's shown represent a large variety of equipments, such as teletypewriters, computers, computer terminals, encryption devices, message switches and message terminals. The majority of data transmission circuits, provided by the DCS today, are at rates up to 9600 b/s. A few requirements exist for rates at 50 and 56 kb/s, and fewer still at higher rates. An ever increasing requirement for transmission circuits at higher data rates is projected. Therefore, a capability is being incorporated in the transmission equipment to accommodate a wide range of user requirements at rates into the megabit per second region.

The DTE interfaces the DTN at Data Circuit-Terminating Equipment (DCE). In today's world, the DCE's are typically modems that have been developed to carry data from a specific DTE through the analog telecommunications network to the destination DTE. If the DTE is a teletypewriter, the DCE is normally a Voice Frequency Carrier Telegraph (VFCT) terminal. If the DTE is a data source providing rates up to 9.6 kb/s, the DCE is a modem capable of operating at the desired rate over Voice Frequency (VF) analog channels. For the still higher rates (50, 56, 64, or 128 kb/s), a group modem could be used to carry the data stream through the 60-108 kHz group channel of Frequency Division Multiplexers (FDM's).

The DTN described in this report is aimed at providing a similar capability through a digital telecommunications network. In this case, the DCE will typically be the Low Speed Time Division Multiplexer (LSTDM). The principal emphasis of this report is on using the LSTDM for digital transmission applications. However, the capability to extend data circuits over analog facilities using appropriate VF or group data modems will continue to be required.

The LSTDM (described in more detail in Section IV.1.b) is highly versatile in the sense that it provides a large variety of interface capabilities and is specified to interface with a wide range of specific DTE's. The function of the LSTDM is to concentrate the mix of user data services entering the DTN into a single high speed synchronous data channel referred to as a Data Trunk. The Data Trunk enters the telecommunications network at the first level multiplex (e.g., the AN/FCC-98 of the DRAMA family) whose output is to be carried through the digital telecommunications network in place of a digitized voice channel.

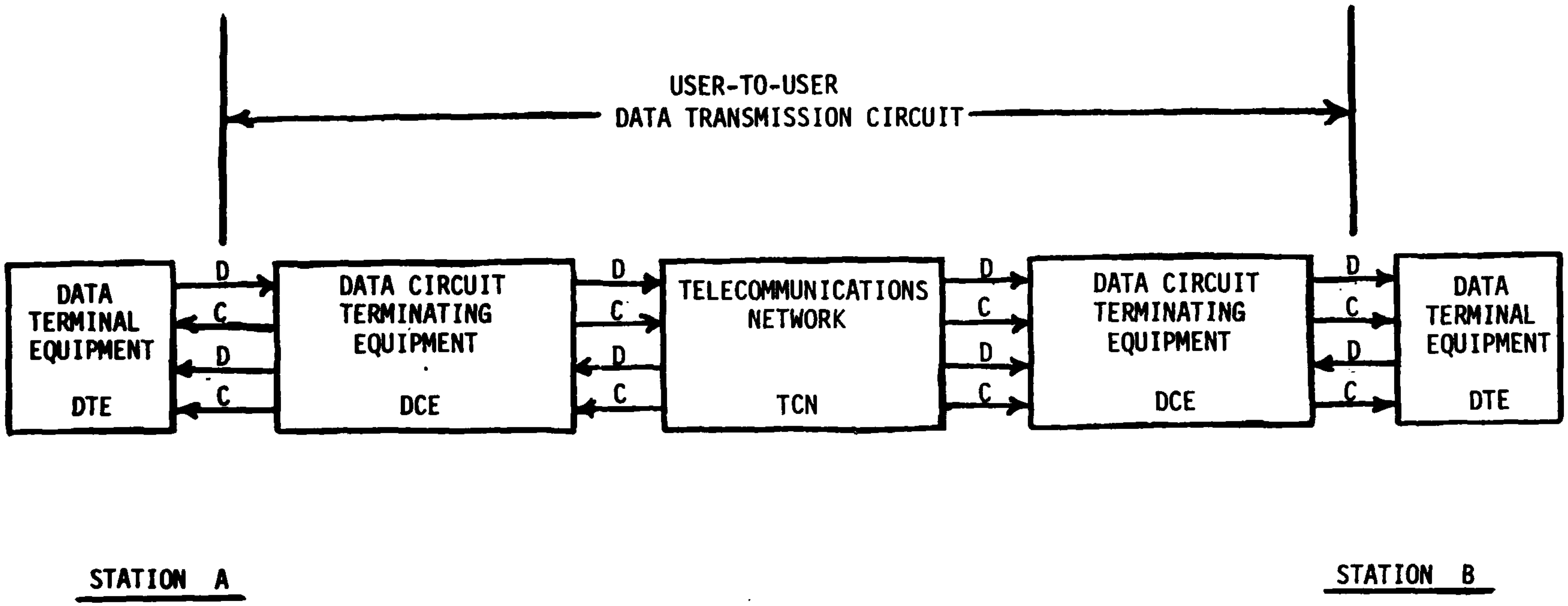
A generalized view of the DCS DTN is shown in Figure 2. This network is a set of interconnected transmission nodes comprising transmission equipment and Technical Control Facilities (TCF). The DTE can be collocated at the TCF or located at a remote user facility. When the users are not collocated with the TCF, the circuits are extended to the user location over local loops using line drivers or VF modems as appropriate. Internodal transmission is provided

over Government-owned or leased transmission facilities. These facilities include a variety of transmission media such as LOS microwave, troposcatter, satellite, submarine cable and terrestrial cable. As the network evolves, the design objective is to maintain a reasonable mix in the selection of transmission to enhance survivability. Survivability aspects of the DTN design are driven by specific user requirements and will be implemented as an integral part of the DCS system design engineering.

A representation of the DTN hierarchy is shown in Figure 3. There is a wide variety of user DTE's, each operating at different data rates and timing modes. The LSTDM provides the DCE function to interface with the various data terminating equipments. The LSTDM will be configured to interface with the specific requirements of the user's DTE. Although the LSTDM has a number of possible combined output data rates, the data trunk rates that are preferred are 56 kb/s or 64 kb/s. These rates are becoming more widely available as leased digital services, can be accommodated through most digital voice switches without impairment, and are compatible and consistent with the transmission rate used to provide PCM digital voice service. In CONUS, 56 kb/s is recommended since it is a U.S. standard commercial rate and is available as a leased digital service. In other geographic areas, such as Europe, 64 kb/s is the rate that is becoming available as a leased digital service and therefore should be considered as the standard data trunk rate.

A digital loop (see Section IV.1) connects the DTE and the DCE. DCE and DTE that have electrical interfaces that meet MIL-STD-188-114 can operate over cable facilities up to several miles in length. Performance tests [1] accomplished by NSA have shown that a balanced interface will drive telephone cable 20 miles at 600 b/s, 12 miles at 1200 b/s, 8 miles at 2400 b/s and 4 miles at 9600 b/s. For longer cable facilities a cable line driver is required. The requirement for a line driver will largely depend on the type and condition of cable being driven. For longer loops, when transmission facilities are provided over carrier (FDM or TDM) facilities, VF or group modems will be required. Most applications will involve transmission over multipair telephone cable facilities on military bases. Thus, in most cases, the loop between the DTE and the DCE will be at most several miles in length, which can be handled by line drivers. Future application will see expanded use of fiber optic cable and appropriate fiber optic cable drivers.

The standard higher levels of the hierarchy in the Government-owned telecommunications network are the first (AN/FCC-98) and second (AN/FCC-99) level multiplexers, digital LOS radio (AN/FRC-170(V)), the digital troposcatter radio (MD-918/GRC modem with various RF equipments), and the Defense Satellite Communications System (DSCS), or leased channels. As described in later sections of this report, digital channels for the DTN will be engineered to operate through these various equipments and alternative transmission media in addition to leased facilities and tariffed wideband circuits. It is envisioned that in Europe, Host Nation Approval (HNA) will be required for all DTN equipment interfacing PTT lines.



D - Data
C - Clock

Figure 1. DTN Functional Diagram

1. 1985 DESIGN

In order to develop a basis for planning the implementation of the DTN by the mid-1980's, a preliminary worldwide network design has been developed. The results of this effort were used as the basis of the DCS 1983 Five Year Program (FYP). This section summarizes the approach and assumptions used in developing this preliminary design, and statistically characterizes the network to provide a model for further description and analysis of the expected user-to-user performance presented in Section III, 3.

a. User Requirements. To identify potential user requirements, a listing of all point-to-point and multipoint data circuits at 32 kb/s and below (including teletype) were obtained from the Defense Communications Agency (DCA) data bases. Separate listings were produced for Europe, Pacific, and the Western Hemisphere (CONUS, Panama, and Puerto Rico). Two DCA data bases were used. The first was the DCS circuit listing, by Command Communications Service Designation (CCSD) number, of all data circuits presently being handled over DCS leased and Government-owned transmission facilities. The second was the Military Satellite Office (MSO) data base which includes circuits that have been approved for planning purposes by the Joint Chiefs of Staff (JCS) to traverse DSCS links. The resulting compilation of circuit requirements was then modified, based on known, near-term, DoD planned facility closures and deactivations, unit moves, and other new circuit requirements not currently reflected in either of the data bases. The resulting numbers of circuits and circuit segments for each area were: Europe 2037, Pacific 1861, and Western Hemisphere 1161.

In the European and Pacific theaters, all data circuits were included. In the Western Hemisphere, only the low speed teletype circuits and data circuits associated with current systems and planned digital upgrades that terminate on Government-owned facilities are included in the requirements list for the DTN. Of a potential 5000 data circuits in the Western Hemisphere, less than 1200 qualified for consideration. The balance of the circuits currently use VFCTs or VF modems over leased voice circuits. A detailed economic analysis would be required to determine the effectiveness of terminating the leased services, and including these circuits in the DTN using high-speed leased transmission facilities. Efforts have not been expended in that area.

A network design was accomplished for each of the three areas using a routing algorithm, developed by DCEC, [15], referred to as ROUTER. The ROUTER program uses the circuit requirement file and the DCS link and node files to determine the most cost-effective transmission route for each circuit. For this preliminary network, the criterion used for routing circuits was to utilize the shortest available circuit path. These paths were obtained from a link file which is a listing of available LOS, tropo, satellite, cable, and leased transmission facilities between DCS Technical Control Facilities (TCF's). The link files used for the ROUTER program were based on planned digital upgrades of the DCS transmission facilities through 1985. The use of analog transmission facilities is required during transition to digital transmission, when no plan to digitize the transmission links

exists, or when survivability considerations dictate. For this network design, the DTN data circuits to be carried over an analog transmission segment were multiplexed into data trunks and extended over the analog facilities using group and VF modems.

b. Multiplex Plan. The LSTDM can be used to multiplex up to 16 low speed (less than 35 b/s to 64 kb/s) data circuits into a combined data trunk. The term "data trunk" will be used henceforth as the identifier of a digital stream comprising time division multiplexed data channels, each operating at a lower bit rate. Based on the capability of the LSTDM to generate data trunks, a preliminary multiplex plan and equipment requirements list was developed from the ROUTER program link file output. The recommended data trunk rate for the DTN is 56 kb/s or 64 kb/s depending upon the geographical area being served. Other rates can be provided by the LSTDM as a data trunk, but these rates should only be considered to meet very specialized requirements. The advantages of standardizing on these bit rates are that restoration is simplified, these rates are compatible with the digital equivalent of a single voice channel, and these rates are becoming widely accepted as a standard offering of the commercial carriers. Initially, the data trunk will not be fully utilized in many cases since there often will be insufficient data users to fill 56 kb/s or 64kb/s. Setting up data trunks in the DTN to operate at other, lower rates will generally not be productive since the basic transmission rate in the telecommunications network is a digital voice equivalent channel. Nevertheless, significant improvement in transmission efficiency will be obtained because a single voice channel will provide transmission for a large number of data users, each of which previously required modems over individual voice channels.

In the preliminary DTN multiplex plan, the LSTDM was generally utilized wherever three or more circuits originated or passed through a DCS TCF. When there were fewer originating circuits, these were extended as subscriber loops to a TCF where multiplexing was planned. In this preliminary work, no attempt was made to "nest" LSTDM's to develop a capability of greater than 16 channels per data trunk. Nesting is accomplished by running the output of one LSTDM into the input of another at the same location. In many cases "nesting" will improve the utilization of transmission capacity, but at the cost of reduced restoration flexibility. In any case, optimization of the network by nesting LSTDM's, selecting specific data trunk rates, and determining the specific routing of the data trunks is considered a function of the final circuit allocation and engineering process.

The resulting FYP listings defined the locations of the end points of the data trunk groups and therefore the quantities of multiplexers, modems, line drivers, and alarm sensor equipments required to implement the network. VF or group data modems are required in those locations where data trunks are extended over analog transmission facilities. VF modems or line drivers are required for remote users to access the networks. Alarm sensors are required for sensing and remoting the LSTDM monitor and alarm signals.

User-to-user data circuits are routed over one or more data trunks, connected in tandem, to traverse the transmission network. The performance of this user-to-user circuit is a function of the number of tandemed data trunks that a circuit traverses. Table I gives a distribution of the number of trunks that the average circuit will traverse in the planned network design. The statistics of the number of data trunks traversed is therefore essential to evaluate a generalized measure of the user-to-user performance. Approximately 95% of all circuits pass over three or less data trunk groups.

The statistics presented in Table I are somewhat biased due to the way satellite and multipoint circuits were included in the network design. User-to-user circuits that traverse satellite links were considered in terms of satellite and terrestrial segments. Each satellite link and terrestrial tail was included as a separate circuit. Thus one user-to-user data circuit that traverses a satellite link may appear in this table as two, three, or four circuits depending upon how it was routed. Similarly, the multipoint circuits in the network design were considered in terms of multiple segments. These "circuit" segments that connected users to hubbers and interconnected hubbers, were counted as individual circuits. This approach was required because the ROUTER program algorithms cannot accommodate multipoint circuits, and each segment of the multipoint circuits is considered as an end-to-end requirement. The network design included 415 multipoint circuit segments.

The net impact of the bias introduced by the satellite and multipoint circuits is that there are actually fewer circuits in the network than indicated by Table I, and the circuits will statistically tend to require tandeming over more data trunks than indicated in this table. However, for purposes of this report, the data is sufficiently accurate to initiate the engineering design of the network.

c. Operations and Maintenance. There is currently underway a DCEC Task being planned to develop certain aspects of a DTN Operations and Maintenance (O&M) concept. The objective of this effort is to define the requirements and the functional elements to accomplish circuit monitoring, fault isolation and circuit restoration. As presently envisioned, DTN Control Centers (DTNCC) will be provided at key transmission nodes. These centers will provide the equipment and personnel to remotely configure and perform diagnostics on the LSTDM and ancillary equipment used to implement the DTN.

d. Multipoint. Asynchronous multipoint circuits are currently implemented using asynchronous hubbers. With the implementation of the DTN, it is not anticipated that this situation will change. Synchronous multipoint circuits are currently implemented using VF modems and analog bridges. Synchronous multipoint data circuit requirements will continue to be satisfied in this way during the early portions of the DTN implementations. A more transmission efficient alternative to satisfying these requirements would be to use a synchronous multipoint hubber. The requirements and performance characteristics of this device needs to be established.

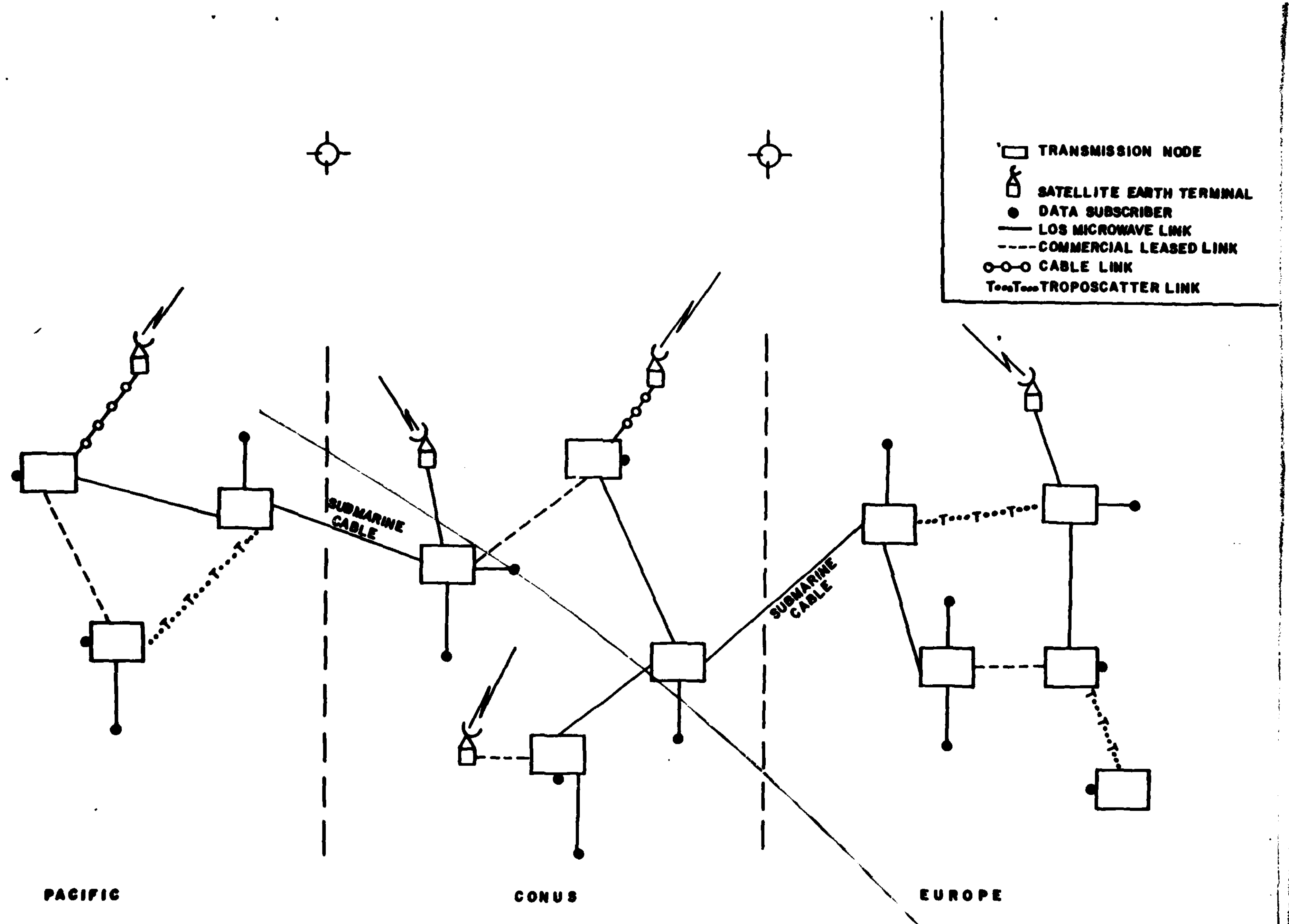


FIGURE 2. DEFENSE COMMUNICATIONS SYSTEM DATA TRANSMISSION NETWORK

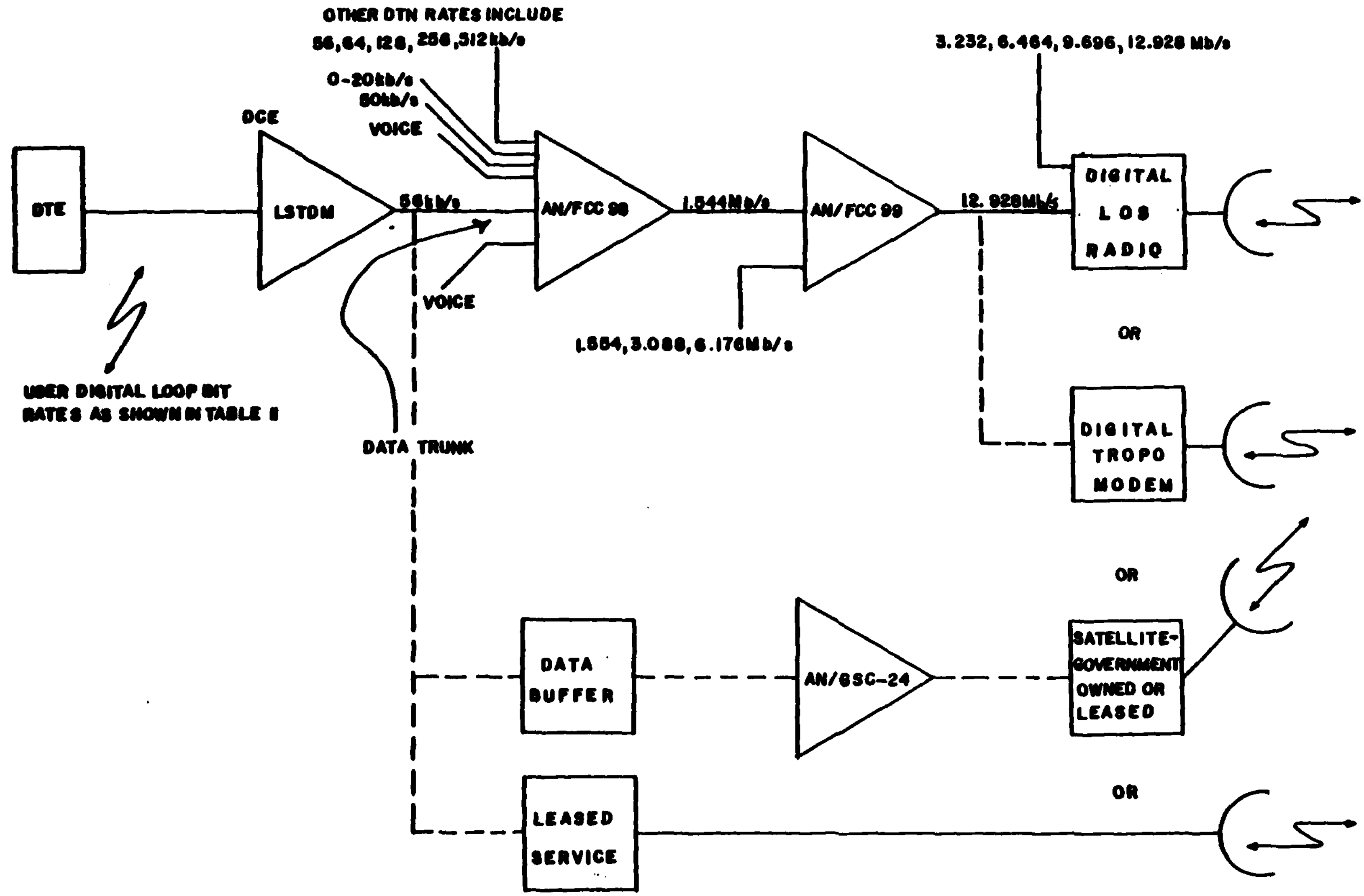


FIGURE 3. TYPICAL DATA TRANSMISSION NETWORK HIERARCHY

TABLE I. DISTRIBUTION OF NUMBER OF DATA TRUNK
PER DATA CIRCUITS FOR FYP-83 DTN

Number of Trunks	Europe (#/%)	Pacific (#/%)	West Hem (#/%)	Worldwide (#/%)
One	1162/57%	1151/61.8%	866/74.6%	3179/62.84%
Two	453/22.2%	418/22.5%	189/16.3%	1060/20.95%
Three	312/15.3%	197/10.6%	73/6.3%	582/11.5%
Four	76/3.7%	61/3.3%	27/2.3%	164/3.24%
Five	20/1.0%	28/1.5%	6/0.5%	54/1.07%
Six	13/0.6%	3/0.2%	-	16/.32%
Seven	1/0.1%	3/0.2%	-	4/.08%
Total Circuits and Circuit Segments	2037	1861	1161	5054

2. USER DIGITAL DATA TRANSMISSION CAPABILITIES

The DTN will provide digital data transmission circuits for those subscribers that meet the interface characteristics as defined in Table II. The interface characteristics defined are transmission rates, signal electrical parameters, and timing modes. These data services have been defined to satisfy near term and future requirements for those users presently being provided service by the analog DCS. It is desirable that future user systems be designed to use the standard transmission circuits. If these "standards" do not meet a particular user's requirements, certain modifications of the characteristics and performance factors are possible but may require long lead times and impose cost penalties that would have to be absorbed by the program being supported.

a. <u>User Rates</u>. The rates provided by the DTN include current standard rates and all user transmission rates identified in the DCS data base that are currently in significant use. The standard transmission rates are preferred for systems now being designed and all future systems. The nonpreferred rates (marked by asterisks in Table II) are included because they are commercial standard rates and/or a large number of terminal equipments are still in use which require nonstandard transmission channels.

The preferred standard rates are 75×2^N up to 9600 b/s, and the 8000N rates of 8, 16, 32, 56, 64, 128, 256, 512, and 1544 kb/s. The DTN transmission rate indicated in Table II as less than 35 b/s does not strictly fall in any of the above data rate or timing mode categories since it is not periodic in any sense. It is a capability to transfer low rate on-off control signals. The most obvious examples are for remote keying of transmitters, or carrying equipment alarms, or terminal control signals.

b. <u>Electrical Parameters</u>. The two electrical interface characteristics that are provided by the DTN are: (1) Non-Return-to-Zero (NRZ) as defined by MIL-STD-188-114 [2], and (2) Conditioned Diphase (CD) as defined by TRI-TAC Specification #TT-A3-7005-0040A [3].

The preferred standard electrical interface is balanced NRZ for data and, where appropriate, clock signals. MIL-STD-188-114 specifies the electrical characteristics for only low level balanced and unbalanced signals. The DCE's (such as the LSTDM) for the DTN are specified to accept only low level signals. Therefore, high level to low level converters will be required for interfacing high level DTE's allowed by MIL-STD-188-100 [4].

A conditioned diphase capability is provided to interface with tactical users (TRI-TAC) at the digital channel level. This capability includes a built-in line driver that enables the LSTDM to operate over a loop up to 4 km long to serve clusters of remote subcribers without the additional cost of a separate line driver or VF modem. The CD capability is provided for the synchronous rates indicated in Table II.

c. <u>Timing Modes</u>. The three interface timing modes that the DTN will accommodate are synchronous, asynchronous and isochronous. These interfaces are defined as timing modes to be consistent with Chapter 12 of DCAC 310-65-1 [5].

TABLE II. DTN USER DATA TRANSMISSION CHARACTERISTICS

Rate	Electrical Characteristics		Timing Modes		
b/s	Non-Rtn to-Zero	Conditioned Diphase	Synchronous	Asynchronous**	Isochronous***
< 35	X				
37.5*	X				
45.45*	X				
50.0*	X			X	
56.8*	X				
61.12*	X				
74.2*	X				
75.0	X	X	X	X	
110	X			X	
134.5	X			X	
150	X	X	X	X	
300	X	X	X	X	
600	X	X	X	X	
1200	X	X	X	X	
1800*	X			X	
2000*	X			X	
2400	X	X	X	X	
3600*	X			X	
4800	X	X	X	X	
7200*	X	X	X	X	
8000	X	X	X		
9600	X	X	X	X	
16k	X	X	X		
19.2k*	X	X	X	X	
32k	X	X	X		
50k*	X		X		
56k	X		X		
64k	X	X	X		
128k	X		X		
256k	X		X		
512k	X		X		
1,544k	X		X		

* Nonpreferred Rates

** Asynchronous data transmission provided at the specific rates indicated using UART.

*** Isochronous data transmission provided by transitional encoding. Isochronous transmission can be provided up to 20 kb/s using the AN/FCC-98 and up to 2400 b/s using the LSTDM.

These timing modes have the same electrical characteristics, but differ in their signal format, clocking arrangements, and how they are accommodated by the network.

(1) Synchronous Mode. The synchronous timing mode interface is characterized by a data signal that is accompanied by a phase related clock signal which is provided by either the data source or the data sink. If the clock is provided by the source, it is termed a codirectional clock. If the clock is provided by the sink, it is termed a counterdirectional clock. Synchronous interfaces between terminals and transmission equipments and between transmission equipments are accommodated in different ways depending upon the equipment configurations. Even though the equipment interface is synchronous, the approach used to accommodate transmission rate offsets may be one of three basic types: slaved, buffered, or pulse stuffed.

(a) Slaved. The slaved interface is truly synchronous since the source (user terminal) clock and the DCE clock are the same. The clock signal can be provided by a station clock, the DTE or the DCE. A slaved synchronous interface minimizes the chance of introducing channel impairments due to timing problems at the DTE/DCE interface. Therefore, a slaved synchronous interface is the preferred synchronous approach in every case where it can be used.

(b) Buffered. The buffered interface is used to accommodate plesiochronous interfaces. Plesiochronous means near-synchronous and implies that the source and sink transmission rates are sufficiently accurate that the accumulated phase difference between the source and sink can be accommodated in a reasonably sized buffer. The clock signal is always codirectional so that the data can be read into the buffer under the control of the source clock and read out of the buffer under the control of the sink clock. Since the clocks have different rates the buffer will eventually over or under flow and data will be lost until the buffer is reset to its midpoint and synchronization reacquired. When data bits are lost or added and not accounted for, for any reason, the circuit will lose Bit Count Integrity (BCI).

(c) Pulse Stuffing. The pulse stuffing interface is used to obtain a synchronous interface when the source and DCE (normally a TDM) have different clock rates. The pulse stuffing approach also uses a buffer, but the buffer is not allowed to underflow or overflow. A way to accomplish this is to assure that the multiplex clock rate is sufficiently high that the buffer never overflows. When the buffer approaches an underflow condition, extra pulses are inserted under the control of the multiplexer. An indication that additional (stuff) pulses have been added is transmitted to the demultiplexer over a control channel, and the pulses are extracted from the user's data stream. Pulse stuffing can degrade performance since the destuff action causes jitter in the output data stream, and errors in the control channel will cause incorrect destuffing actions and thereby cause loss of circuit BCI.

The DTN provides slaved or buffered synchronous interfaces for the rates indicated in Table II. It is noted that a characteristic of the CD signal is that both data and clock are carried on the same signal and therefore all CD synchronous interfaces have codirectional clocks and are buffered.

(2) Asynchronous Mode. The asynchronous timing mode interface is characterized by intermittent data streams that are character-coded in start-stop formats. The time between characters is normally filled with an all-mark sequence of pulses. DTE's that require asynchronous interfaces generally use relatively inaccurate internal clock sources. The data signal is provided to the DTE and accepted from the DTE without a clock signal. The DTN asynchronous timing mode shown in Table II will accept character oriented start-stop digital signals at 110 b/s, 134.5 b/s and standard 75 x 2^N rates up to 19.2 kb/s. The characters can have 5, 6, 7, or 8 data bits, a 1 bit start pulse and a 1.0, or 2.0 bit stop pulse. The asynchronous port in the DTN is implemented using a Universal Asynchronous Receiver/Transmitter (UART). The UART digitally strips the start and stop pulses from the character and synchronously multiplexes the remaining data on the data trunk. At the demultiplexer the start and stop pulses are reinserted and the data is clocked out to the user. The advantage of this approach is that it provides a very efficient channel; however, the channel is limited to specified parameters in terms of rate, word and start and stop pulse lengths. Applications for users requiring asynchronous circuits that will accommodate changes in format or rate will have to be engineered using the Isochronous timing mode discussed in the next paragraph.

(3) Isochronous Mode. The isochronous timing mode interface is similar to the asynchronous timing interface except that the data does not necessarily have to be character encoded. Isochronous data signals are accommodated by encoding the data to a higher synchronous rate using transitional encoding or pulse stuffing and then synchronously multiplexing the encoded synchronous data into the data trunk. The CCITT recommended technique for transitional encoding is used to implement the Isochronous ports of the LSTDM. The selected implementation uses three bits to encode the transition and a synchronous port rate four times the nominal user data rate. This approach has the disadvantage that it is channel inefficient, but it has the advantage that it provides the user a rate-transparent circuit that can be used for either isochronous or asynchronous timing modes. Transitional encoding will also introduce up to 10% isochronous distortion. To minimize the accumulation of distortion on circuits that traverse multiple data trunks, signals will be tandemed (through routed) at the synchronous rate.

The LSTDM will accommodate isochronous data circuits up to 2400 b/s. It is anticipated that this capability will be extended to rates as high as 4.8 kb/s. Isochronous circuits may also be provided by the AN/FCC-98 using the isochronous data port module. This port module encodes the user data into a synchronous rate of 64 kb/s, uses a 3-bit transitional encoding technique, and will accommodate user circuits up to 20 kb/s.

3. PERFORMANCE OBJECTIVES

This section provides a quantitative estimate of the user-to-user performance of the DTN. These estimates have been included to establish performance objectives for the implementation of the network and are based on the network model developed in DCEC TR 12-76 [6] and the draft performance standard MIL-STD 188-XXX [7]. Additional work is currently being conducted at DCEC to finalize the performance standard.

In a digital data network, the criteria of performance are best described in terms of availability, delay, bit count integrity (BCI) and a measure of bit error rate (BER). Performance is a function of the circuit rate, timing mode, transmission media traversed, equipment, equipment configurations, distance and routing. To develop a quantitative measure of performance, therefore, it is necessary to develop a typical geographical and equipment configuration that will allow the identification and consideration of the many sources of end-to-end performance degradation. In the FYP 83 network design there are 726 data trunks to serve approximately 5000 low rate data circuits. A data circuit can traverse up to 7 data trunks but 95% traverse less than 3 data trunks. Further, of the 726 terrestrial data trunks, 96% will traverse less than 10 LOS microwave links and 5 troposcatter links. Based on these statistics a performance bound can be calculated that will apply to approximately 90% of the user circuits. The performance of specific circuits must be considered on a case-by-case basis. A more detailed analysis of the end-to-end performance of the DTN is planned to be addressed in a future report.

a. Bit Error Rate (BER). A frequently used measure of the effect of errors is the average BER. This measure is appropriate if transmission errors are uniformly distributed (i.e., spread uniformly throughout the received bit stream) and their occurrences can reasonably be assumed independent. This assumption is reasonable for data transmission via digital satellite channels; however, line-of-sight and troposcatter links which make up the terrestrial DCS do not always behave in this way. For these links, errors are mainly caused by fading and electromagnetic disturbances and thus occur in bursts. These bursts are very poorly described by average BER. A more useable measure than average BER is the probability that the BER is above some threshold value that defines error burst. Such a measure is more useable than an average BER measure since it describes the channel in terms of the percentage of time spent in error bursts. Unfortunately, this measure is still deficient in that it tells nothing about the temporal distribution of bursts. One cannot determine from such a cumulative measure whether each transmission will be disturbed by a short error burst or whether only an occasional transmission will be obliterated by a much longer burst.

In order to provide interim guidance in this matter, DCAC 300-175-9 [8] is being modified to include performance BER criteria for digital data circuits provided by the DCS. The modification [9] provides the following terrestrial data circuit performance criteria where the circuits are provided over analog or digital transmission facilities.

Rate (kb/s)	Average BER	Block Error Rate	Block Size (Bits)	Sample Interval (Bits)
1.2 to 9.6	10^{-5}	10^{-2}	10^{3}	10^{6}
16 to 512	10^{-6}	10^{-3}	10^{3}	10^{7}

[9] (Table 5b) also specifies that satellite link performance shall provide data circuits with a BER threshold of 10^{-5} (averaged over 10^{9} contiguous bit intervals measured at the circuit data rate), and block error rates less than or equal to 3×10^{-3}. A data circuit traversing a satellite link will therefore provide a BER no better than the satellite segment of the circuit.

b. Bit Count Integrity. Loss of bit count integrity (BCI) is best characterized by its frequency of occurrence, or inversely, the time between such occurrences using the statistical mean, i.e., the mean time to loss of BCI (MTTLBCI). The procedure utilized to allocate the MTTLBCI was to assign an objective of 24 hours for the DCS global reference circuit [10]. The four major sections of the global reference circuit were allocated to the link level. The resulting MTTLBCI objectives for LOS and tropo links are 4800 hours and 800 hours, respectively. A data trunk consisting of 10 LOS links and 5 tropo links would have a MTTLBCI objective of 120 hours. A data circuit transiting three data trunks will have a MTTLBCI objective of 40 hours. Further, since there is no reason to believe that a data trunk traversing a satellite would impose a MTTLBCI objective of less than 120 hours, a data circuit traversing three terrestrial and one satellite data trunks should therefore provide a MTTLBCI objective of at least 30 hours.

c. Delay. Transmission delay is introduced on a data circuit as a function of distance (propagation time) and the amount of data buffering used for digital processing (multiplexing, error control, etc.) and network synchronization. Propagation delay is independent of the data circuit rate but delays introduced by data buffers, which are usually the same for all rates, are inversely proportional to rate. The total delay is therefore a complex function of the geographical, media and equipment configurations used. Table III provides an estimated upper bound for both the nominal and maximum delays that can be expected on DTN data circuits. These results apply to a circuit model consisting of three terrestrial data trunks and one non-ECCM satellite data trunk. These estimates, therefore, provide transmission delay design goals applicable to 90% of the data circuits provided by the DTN. Estimated delays for specific circuits must be calculated on a case-by-case basis.

Data circuits requiring ECCM protection over satellite links will be provided forward burst error encoding at the circuit rate. This coding process will contribute significantly to the delay that will be encountered. These delays are not currently well defined and, therefore, a user-to-user transmission delay design goal cannot be estimated.

Asynchronous and isochronous circuits that are transitionally encoded will experience delays associated with the synchronous encoded rate. For example, from Table III, a 75 b/s asynchronous or isochronous circuit transitionally encoded at 300 bps will have a maximum one terrestrial data trunk delay of 115 ms. Clearly if delay is a significant problem for the user and sufficient capacity is available to encode the circuit at 2400 b/s, the corresponding maximum delay can, and should be, reduced to 30 ms by using this additional capacity.

TABLE III. ESTIMATED DTN TRANSMISSION DELAY DESIGN GOALS FOR SYNCHRONOUS DATA USERS AT TYPICAL RATES

Circuit Data Rate	One Terrestrial Data Trunk (ms)		One Satellite Data Trunk (Non-ECCM) (ms)		Three Terrestrial and One Satellite Data Trunk (ms)	
	Nominal	Maximum	Nominal	Maximum	Nominal	Maximum
75	175	400	420	675	945	1875
300	55	115	300	385	465	730
1200	25	40	270	310	345	430
2400	20	30	270	300	330	390
4800	15	25	265	295	310	370
9600	15	20	265	290	310	350
16000	15	20	265	290	310	350
32000	15	20	260	290	305	350

d. Availability. Availability is the total fraction of time that the system is not in an outage condition. An outage is defined [6] as either loss of path continuity for a period in excess of one minute or error rate on the mission bit stream in excess of 10^{-6} for a period in excess of one minute. The DTN design objective is to provide an end-to-end availability of .99. Based on the availability of LOS and tropo links provided in [7] and the reliability requirements specified for the LSTDM, the availability for a data trunk consisting of 10 LOS and 5 tropo links is .998532. Therefore, a data circuit traversing three data trunks will result in a node-to-node availability of .9960. [9] specifies a satellite circuit availability of .997 such that the availability of a circuit traversing three terrestrial and one satellite data trunks is .9925. In order to achieve the user-to-user availability requirement of .99 the loop segment at each end of the circuit will require an availability of .999.

4. INITIAL IMPLEMENTATION

The Data Transmission Network described in the preceding section consists of approximately 800 data trunk groups, and provides trunking for over 5000 data circuits worldwide. The objective of this section is to propose an initial implementation that will serve as a field trial and will provide a basis for development of a finalized operations and maintenance concept for the mature DTN. The initial implementation will also enable a detailed analysis of specific user requirements to be provided by the DTN and serve as a test bed to obtain performance data. Sites were selected such that interfaces with all types of transmission facilities would be encountered. The various types of transmission facilities in the initial implementation include:

- DCS terrestrial digital transmission facilities using representative digital multiplexers.
- DSCS digital transmission facilities that provide both non-ECCM and ECCM capabilities.
- Leased digital facilities (WAWS, CAWS, DDS, etc.).
- Undersea cable systems.
- Analog and leased analog (FDM) transmission facilities using VF and/or Group modems.

It should be noted that the further development of the initial implementation is currently being accomplished under the auspices of the DTN working group. Although some of the data trunks described in this section have been changed and some have been added, the objectives of the effort are being maintained.

a. Description. Based on the above requirements, a "strawman" DTN initial implementation was developed, which is shown in Figure 4. The network interconnects 14 TCF's with 14 internodal data trunk groups and provides 156 data circuits on a worldwide basis. The data rates of these 156 circuits cover a wide variety of the data service to be provided by the DTN. The low speed data rates provided by the DTN and the rates of the circuits in the initial implementation are shown in Table IV. The LSTDM will accommodate all except the six 3200 b/s circuits that serve NATO users. These circuits are at nonstandard rates and will continue to be implemented as they currently are. Of the 156 circuits, 57 are encrypted. The crypto equipment and the number of circuits for each are shown in Table V. The majority of the encrypted circuits (50 of the 57) use the KW26's, KG13's, and KW7's. The LSTDM has been specified to be compatible with these equipments.

The network contains typical transmission interface configurations which are briefly described in the following paragraphs and shown in Figure 4. The initial implementation will require timing subsystems at those locations where synchronous multiplexing is accomplished. These locations are also indicated in Figure 4.

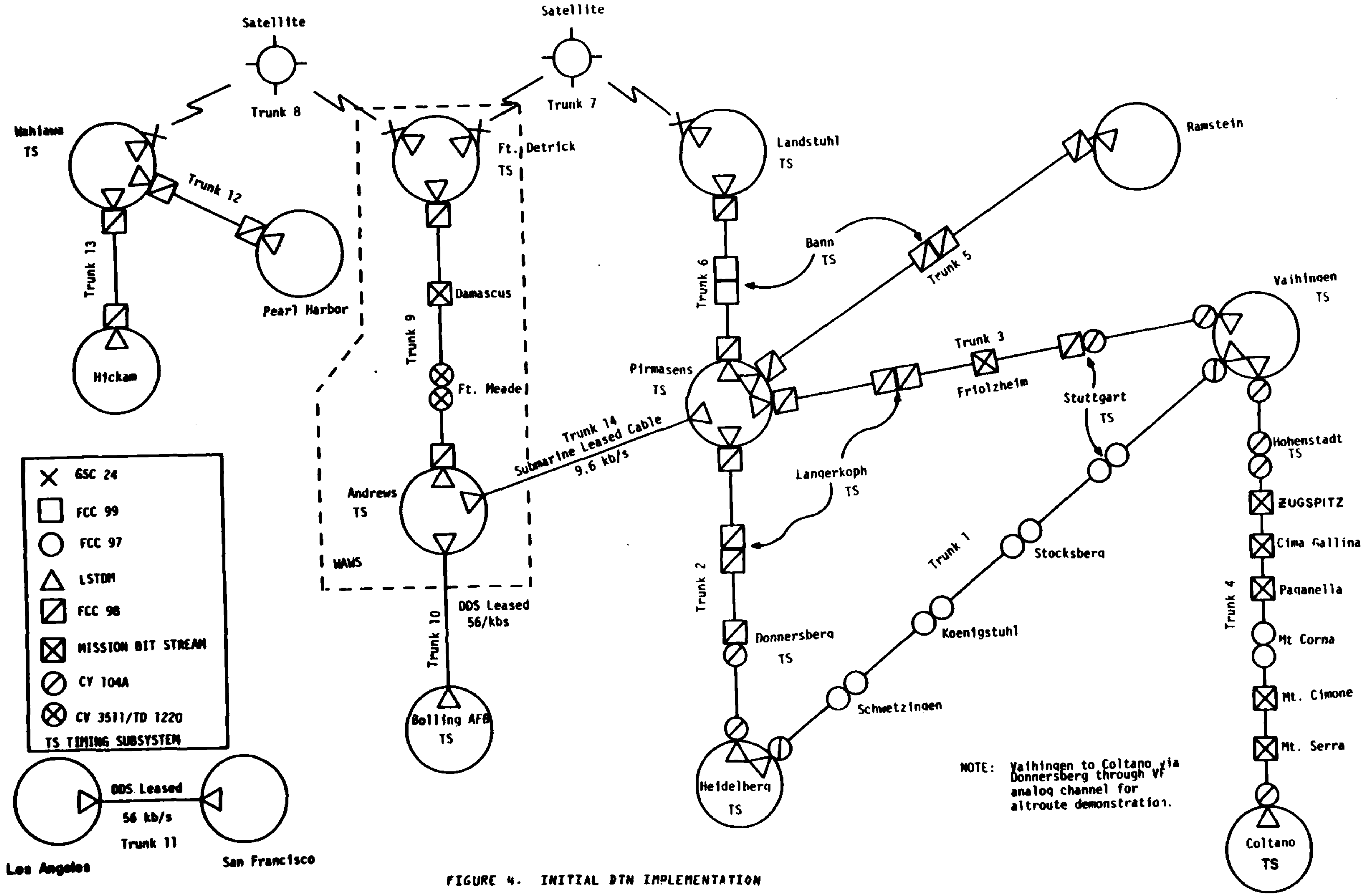


FIGURE 4. INITIAL DTN IMPLEMENTATION

TABLE IV. INITIAL IMPLEMENTATION CIRCUITS BY USER RATES

Rate(b/s)	# Circuits	Rate(b/s)	# Circuits
		300	6
37.5	-	600	3
		1200	29
45.45	4	2400	12
		3200	6
50	3	4800	5
56.8	-	7200	6
61.12	22	9600	7
74.2	7	16 k	-
75	34	19.2 k	1
110	-	32 k	-
150	11	---	-
			156 circuits

TABLE V. INITIAL IMPLEMENTATION CRYPTO EQUIPMENT

Crypto	# Circuits	Crypto	# Circuits
KW 7	4	KG 34	2
KG 13	23	KG 36	2
KW 26	23	KG 37	1
KG 31	1		
KG 33	1		
			57 circuits

(1) DCS Terrestrial Digital. Early digital DCS terrestrial transmission upgrades used CY-104A and AN/FCC-97 multiplexers, while later transmission upgrades will use AN/FCC-98 and AN/FCC-99 multiplexers. The data trunks shown in Figure 4 between Vaihingen and Coltano, Vaihingen and Stuttgart, Vaihingen and Heidelberg, and Heidelberg and Donnersberg are routed over the earlier CY-104A and AN/FCC-97 equipments. All other data trunks in the network that are routed over DCS terrestrial digital transmission will interface with the AN/FCC-98 multiplex equipment. Further, there are typical examples of through-routing data trunks at intervening transmission nodes at the data group (56 kb/s or 64 kb/s), digroup (1.544 Mb/s) or baseband (radio) level.

(2) Leased Digital Systems. The network includes the use of two leased facilities: Washington Area Wideband System (WAWS) and the AT&T Digital Data System (DDS).

The WAWS comprises leased transmission media and Government-owned first and second level multiplexers. The first level multiplexer is the AN/FCC-98, and the second level multiplexer is the CV-3511/TD 1220. The data trunk through the WAWS system is between Andrews AFB and Ft. Detrick.

Under the DDS, the Bell System plans to provide digital channel leases between 96 metropolitan areas (as of March 1979, 53 areas were being served). A typical inter-area application of the DDS for the pilot network would be a circuit between Andrews AFB and Bolling AFB. A longer distance inter-area application would be between Los Angeles and San Francisco.

(3) DSCS. Low speed data circuits traversing the Government-owned satellite link will be multiplexed into 56 kb/s or 64 kb/s data trunks for transmission. Two typical applications for the initial network would be data trunks carried on the Landstuhl-Ft. Detrick and the Ft. Detrick-Wahiawa satellite links.

(4) Undersea Cable Systems. Currently almost all of the known data circuits crossing the Atlantic are handled by channel packing systems at either 4.8 kb/s or 9.6 kb/s. Since this represents one potential application, if only for restoral purposes, a typical application would be between Andrews AFB and Pirmasens to carry the circuits of DCS Channel Packing System (submarine cable).

(5) Analog Facilities. The use of VF channels and modems for providing data trunk groups is a valuable means of achieving quick restoration, and could potentially reduce some of the timing and synchronization requirements. The Vaihingen to Coltano data trunk can be routed via the DEB I digital LOS links. Alternatively, it could be routed to Donnersberg and then to Coltano over analog tropo FDM facilities. This altroute could be used to demonstrate restoral capabilities using analog channels over a relatively long multilink (LOS and tropo) trunk.

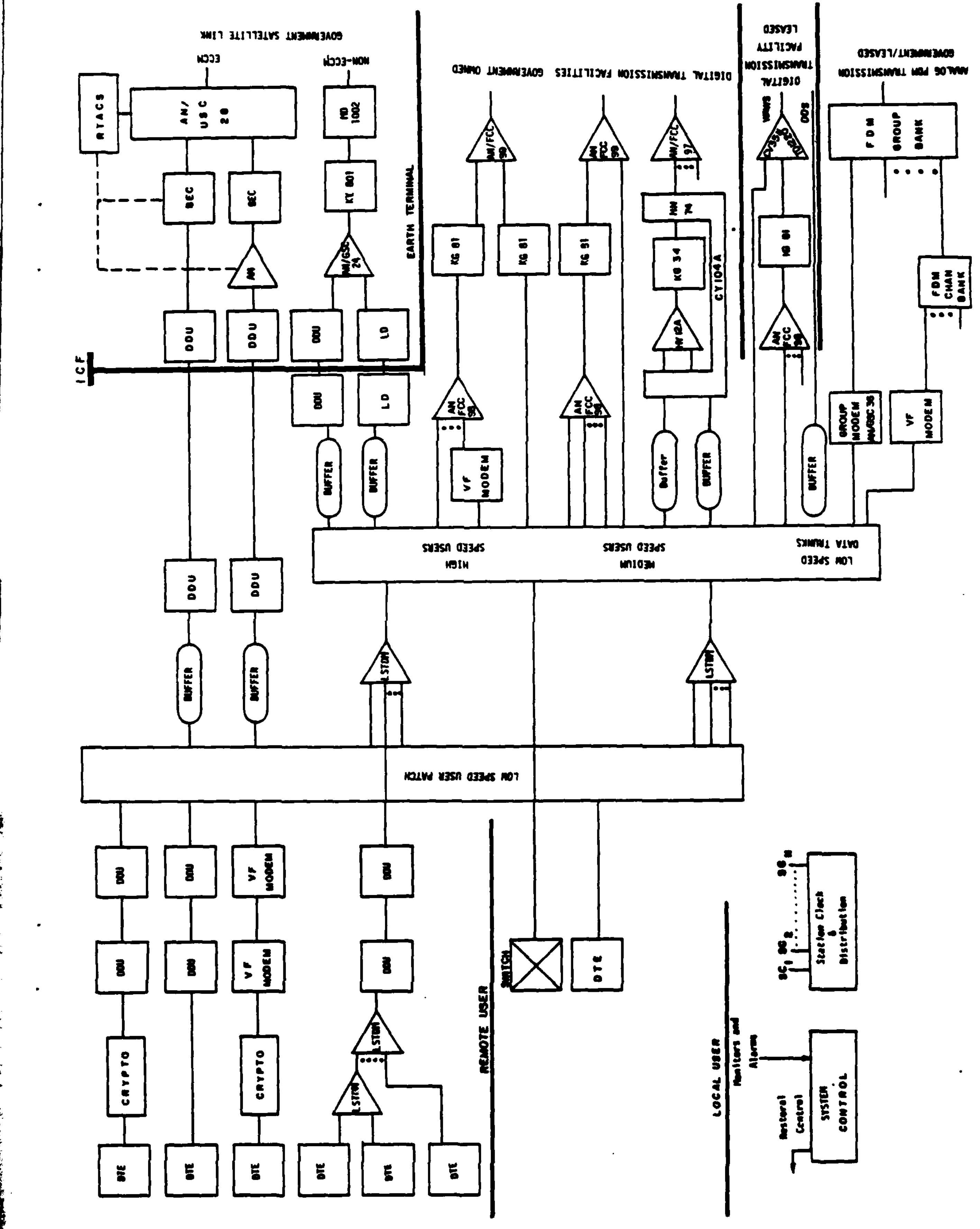


Figure 5. Data Transmission Network Node Equipment Configurations

IV. EQUIPMENT CONFIGURATIONS

This section describes the various transmission equipment configurations that can be used to provide data transmission. Figure 5 is a functional representation of a typical interface found in a DCS transmission facility. Actually this representation is atypical in the sense that few, if any, transmission nodes in the network will have the variety of transmission facilities and user terminations indicated in this figure; it, however, illustrates the many equipment variations that will be encountered in the DTN in order to serve the needs of the data users. The performance of data transmission provided by the DTN is a function of the capabilities of these equipments to interoperate in specific configurations. The following paragraphs discuss user access, channelization, network synchronization, and the various transmission facilities shown. A technical description of the various equipments as well as their interface and performance characteristics are intended to be provided in a supplemental report, as discussed in Section II.

Figure 5 is organized with the data users to the left, the tech control and transmission related equipment in the center, and the transmission media to the right. Consider first the data users (identified as the DTE's). These can be categorized as either local or remote. For the purposes of this report local terminals are defined as those data terminals that can be served directly by the transmission equipment over local cable facilities, and remote users are those that require line drivers, VF modems, or other transmission facilities to access the DTN node. The distance the DCE can reliably drive a digital signal is dependent on the data rate, type of cable, and the condition of the cable.

The DTE's are defined by their data rate, timing mode, and electrical interface characteristics. The range of terminal characteristics that can be accommodated is specified by Table II; the equipment ranges from teletype terminals to ETS/DSN/DDN switches. A great many of the data circuits are encrypted and the actual data terminal/transmission interface is defined by the COMSEC equipment interface. It is planned that a follow-on report will address the interface characteristics of the predominant COMSEC equipment that will interface with the DTN.

The center of Figure 5 depicts three levels of time division multiplexing. These multiplexers provide the digital channelization that will provide user data circuits between transmission nodes. Low speed data circuits (64 kb/s or less) are multiplexed into data trunks. The normal data trunk rates for the DTN are 56 kb/s and 64 kb/s. Data trunks and user circuits at selected rates between 56 kb/s and 512 kb/s are multiplexed into 1.544 Mb/s digroups by the AN/FCC-98 (first level multiplexer), and digroups are multiplexed into mission bit streams for internodal transmission by the AN/FCC-99 (second level multiplexer). As discussed later in this section, different equipments are used in some portions of the transmission network but in general the digital hierarchy is the same.

The DTN is a synchronous system. Each transmission node is provided (or slaved to) an accurate station clock. All digital data signals transmitted

from a node are synchronous with the station clock. All received digital signals from other nodes that will be through-routed are phase-equalized to the station clock using data buffers. User terminals requiring synchronous data circuits are normally slaved to the network. Asynchronous and isochronous data circuits that are accepted by the network need not be slaved to the network. These data circuits are encoded into a standard synchronous rate for transmission through the network.

The right side of Figure 5 shows the predominant internodal transmission facilities that will be used to support the DTN. For the DTN in the 1985 time frame, the predominant transmission facilities that will be available include transmission links over digital DSCS, terrestrial digital DCS, leased digital facilities, and Government-owned and leased analog facilities.

The digital DSCS facilities will accommodate two categories of user circuits: non-ECCM and ECCM circuits. The non-ECCM low speed circuits will be multiplexed into data trunks of 56 kb/s for transmission over the satellite links, using the MD1002 modem. Data trunks for satellite links are multiplexed/demultiplexed at the DCS TCF serving the earth terminal. A data buffer is provided to compensate for satellite delay variations and is required to accommodate a synchronous interface with the terrestrial portion of the DTN. Because of space considerations the buffers will normally be located in the serving TCF. There are configurations where the earth terminal and the serving TCF are collocated, and a line driver will not be required to traverse the TCF/ET interconnecting facilities (ICF). Where the TCF and ET are not collocated, the Digital Distribution Unit (DDU) may be used to accommodate low speed data trunk and user circuits up to 64 kb/s. For data rates above 64 kb/s (128 kb/s - 1.544 Mb/s) no specific device has been identified. It is noted however, that there are a multitude of military and commercial line drivers and modems that could be used to satisfy their requirements.

Whatever specific device is selected, its interface and performance characteristics must be evaluated to maintain control of the DTN user-to-user performance. The suggested use of the DDU should not be construed to imply that a separate line driver will be required in every case. There are certain applications where meeting the baseband interface of MIL-STD-188-114 will be adequate. These circuits will be engineered on a case-by-case basis. ECCM circuits are all 50 kb/s or less and should be individually sent to the ET using an appropriate line driver or modem. These circuits will interface directly with either the AN/USC-28 (ECCM satellite modem) or the Adaptive Multiplexer (AM). The AM has the capability of dropping individual input data circuits and adjusting the aggregate rate to maximize ECCM protection.

These circuits may also be passed through the Burst Error Coder (BEC). The BEC provides forward error correction coding and data interleaving to provide additional protection against jamming or transmission perturbations. The BEC is functionally located between the AM or DDU and the AN/USC-28, but interfaces only the AN/USC-28. The AN/USC-28, BEC, and AM are controlled by the Real Time Adaptive Control System (RTACS) which adapts to changing ECCM transmission and loading conditions. It is noted that some ICF's are planned for implementation using synchronrous multiplexers (AN/FCC-98, AN/FCC-100(V), etc.) which in effect makes the ET the serving TCF. In such configurations the ET will also have to provide appropriate buffering.

The DCS digital transmission facilities are implemented with two different types of equipment, depending on when the digital upgrade took place. Early transmission upgrades used the TSEC/CY 104A (first level multiplexer) and AN/FCC-97 (second level multiplexer). Recent and future DCS transmission upgrades have and will use the AN/FCC-98 (first level multiplexer) and AN/FCC-99 (second level multiplexer). Up to 12 of the 24 VF channel modules provided by the AN/FCC-98 can be replaced with data modules; however, only 5 of the 24 channel modules can be replaced with data modules in the CY-104A. (A modification to the CY-104A has recently been developed which when implemented will expand the data channel capability to 10 modules.) Channels for the DTN will be provided by low speed data trunks on user circuits using the AN/FCC-98 multirate synchronous data module at rates of 56, 64, 128, 256, and 512 kb/s. The AN/FCC-98 data module has a ± 64 bit buffer to accommodate the clock rate difference between the source and sink signals. Ports within the AN/FCC-99 will provide user data circuits at 1.544 Mb/s. The CY-104A and the AN/FCC-97 multiplexer have capabilities similar to the AN/FCC-98 and AN/FCC-99, except that the synchronous data module for the CY-104A provides channels of 32, 48, 56, or 64 kb/s. The data module has only a one-bit phasing buffer which is not sufficient to maintain synchronization for the synchronous DTN, and therefore an input buffer is required. A VF modem can be used on the VF channels to provide DTN data circuits or trunks at standard rates through 16 kb/s.

There are many digital leased services available to support the DTN. Figure 5 depicts the AT&T Digital Data Services (DDS) and the Washington Area Wideband System (WAWS) as two typical examples for the purpose of addressing leased service for this report. The AT&T DDS provides a private line, full duplex, point-to-point transmission service at synchronous rates of 2.4, 4.8, 9.6, 56 kb/s, or 1.544 Mb/s. The electrical characteristics of this interface are defined by Electronics Industry Association (EIA) standard RS 232C and RS 334. The DDS is a synchronous network slaved to a master clock in Hillsboro, Missouri. User data terminals that are provided service by the DDS are also slaved to the transmission network. In those cases where the DDS is used to extend DTN data circuits, a buffer will be provided to compensate for differences in clock rates. Since both networks operate from similar, highly accurate clock sources, only a small amount of buffering is required.

The WAWS is a digital transmission network, similar functionally to the DCS overseas digital transmission facilities, but different in its implementation. The AN/FCC-98 (first level multiplexer), trunk encryption device (TED), and the CV 3511/TD 1220 (second level multiplexer) are Government-owned, but the internodal transmission facilities are leased. The CV 3511/TD 1220 was used in this network for two reasons. First, when the implementation was started, the AN/FCC-99 was not available and there were nonstandard user requirements to be satisfied. Second, the TD 1220 is a programmable synchronous multiplexer that can be adapted to a wide range of user data rates, and the CV 3511 is basically a pulse stuffer that allows the user to access the network without requiring timing slaved to a common network clock.

The Government-owned and leased analog transmission facilities will provide standard analog VF (.3-3 kHz) and group (60-108 kHz) channels. Where digital transmission facilities are not available or special performance characteristics are required, group and VF modems will be used to provide data transmission facilities. There are two military group data modems available. The AN/GSC-36 group data modem provides digital channels at the standard user DTN transmission rates of 56, 64, 112, and 128 kb/s. The AN/USC-26 provides transmission rates of 38.4, 50, 76.8, and 153.6 kb/s. The AN/GSC-36 is a modified version of the AN/USC-26 that will be used to implement the DTN since it provides rates compatible with the LSTDM. The AN/USC-26 can be field modified to be an AN/GSC-36 by replacing cards. Any standard synchronous VF modem can be used at rates of 1.2, 2.4, 4.8, and 9.6 kb/s. For special applications, the AN/GSC-38 VF modem can be used to provide 16 kb/s data circuits. Tests have shown that the AN/GSC-38 modem will provide sufficiently low error rates on a large percentage of channels to satisfy secure voice requirements, but care must be exercised in selecting VF channels for those applications where 10^{-4} to 10^{-6} BER is required for data circuits. The use of VF modems to engineer data circuits over analog facilities provides improved survivability because of the large number of VF circuits available for restoral.

1. ACCESS AREA

In most applications a transmission segment is required to connect the user's DTE with the DCE at a DCS transmission node. Several configurations are possible. The simplest is the case in which the DTE is located at the transmission node. Since the transmission distance is relatively short, the two equipments can be directly connected. The allowable distance between equipments is a function of the electrical interface characteristics of the equipment and the transmission facilities used.

As discussed in Section V, the electrical characteristics for all DTN baseband NRZ interfaces are defined by MIL-STD-188-114 [2] which allows both balanced and unbalanced operation. Figures 6 and 7 depict modulation rate versus cable distance for balanced and unbalanced connections. These curves were excerpted from the MIL-STD-188-114 appendix, which is not a part of the standard but is provided to illustrate operation over typical cable facilities. Figure 6 (balanced) is based on empirical data using 24 AWG telephone cable terminated in a 100 ohm resistive load. The curve does not account for channel impairments that can be introduced by older cable facilities. In most practical cases, the operating distances at lower modulation rates may be extended to several miles. Tests performed on the DRAMA equipment [11] have shown that for NRZ interfaces the maximum cable (RG108) length is about 360 feet for dat rates at 12.928 Mb/s and 1600 feet for data rates of 1.544 Mb/s. Performance tests [1] accomplished by NSA have shown that a balanced MIL STD 188-114 interface will drive telephone cable 20 miles at 600 b/s, 12 miles at 1200 b/s, 8 miles at 2400 b/s and 4 miles at 9600 b/s. Figure 7 (unbalanced) is based on calculated and empirical data. The unbalanced interface is appropriate for lower rates and for applications where the length of cable is relatively short. In most practical cases,

the operating distances may be extended to several miles. It is emphasized that in either case the length of cable that can be driven is dependent on the type and condition of the cable. In general, however, a balanced interface will provide better performance and is recommended. However, since data and clock must be carried in both directions, four cable pairs are required. For installations where the number of cable pairs is limited, an unbalanced interface can be used. In the case of long distances a cable driver should be used.

A number of commercial devices are available such as cable drivers, line drivers, modem eliminators, and limited distance modems. Essentially, these devices are modems, but are designed to operate over relatively high quality, physical (copper cable) facilities and are therefore considerably less expensive than standard VF channel modems. These cable drivers have standard interface characteristics on the equipment side toward the DTE and the DCE, and operate over the cable facilities using various types of line modulation. For the purpose of the report, we have shown and assumed the use of the DDU. The DDU has been recently developed by the Air Force for use over the DSCS interconnect facilities and is discussed further in section IV.1.a.

In those cases where the user is beyond the available cable facilities, two alternatives are available. If the number of user DTE's is small, standard voice frequency modems should be used to connect the DTE via a voice frequency channel to the nearest DCS transmission node providing DTN access. For those applications where several DTE's are collocated at a distance from the DTN node, it would be possible to locate a LSTDM with the DTE's and combine them onto a single digital stream which is then connected to the DCS using a single line driver or VF modem. The LSTDM has a built-in conditioned diphase (CD) line driver on the aggregate side to provide this capability without the use of a separate line driver. The LSTDM is discussed further in Section IV.1.b.

The selection of these various alternatives is highly dependent on local conditions and specific equipment requirements. Therefore, each connection of the DTE to the LSTDM must be individually considered and engineered to assure effective operation.

a. Digital Distribution Unit (DDU). The DDU [12] provides data communications at selectable synchronous rates up to 64 kb/s and asynchronous rates up to 2400 b/s, as shown in Table VI. There are actually two types of DDU: one provides for data rates that are the standard rates 75 x 2^N up to 19.2 kb/s, and the other provides for the 8000N data rates of 8, 16, 32, 56, and 64 kb/s and 50 kb/s. These units will accept synchronous interface for all specified rates and asynchronous interface for the 75 x 2^N rates from 75 to 2400 b/s.

The DDU is designed to operate over unloaded, unconditioned metallic wire pairs 19 to 26 gauge. At 19.2 kb/s and below, it will operate on cable as small as 26 gauge and above 19.2 kb/s on cable as small as 24 gauge. The DDU can operate 4-wire full or half duplex at all rates and 2-wire half duplex

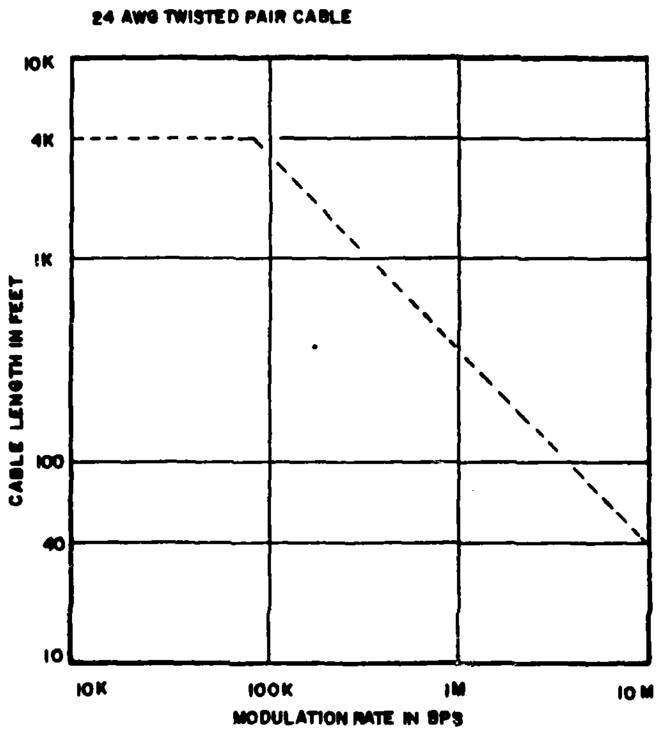


FIGURE 6 MODULATION RATE VERSUS CABLE LENGTH FOR BALANCED VOLTAGE DIGITAL INTERFACE CIRCUIT

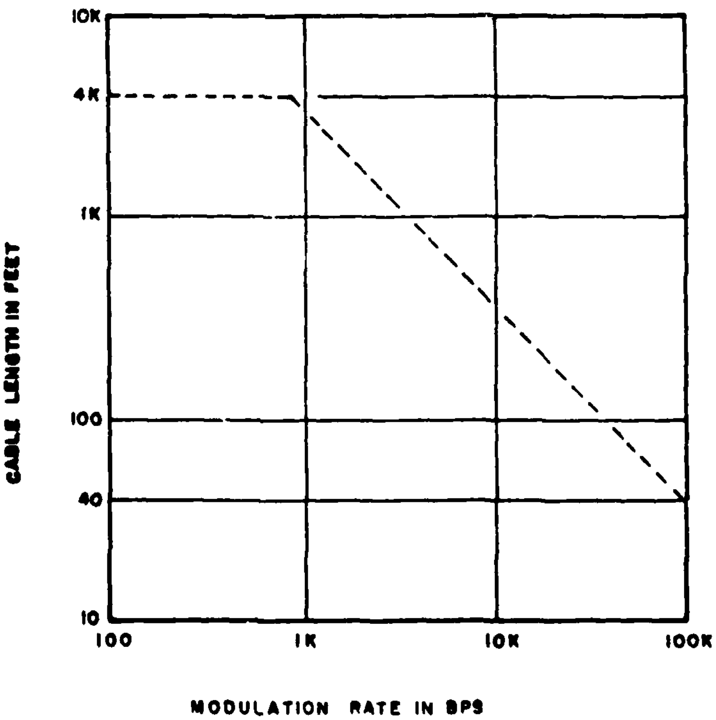


FIGURE 7 MODULATION RATE VERSUS CABLE LENGTH FOR UNBALANCED VOLTAGE DIGITAL INTERFACE CIRCUIT

at 1200 b/s or below. The DDU comes in individual Type 1 modules that can be placed on a desktop or wall-mounted. The Type II unit is a rack-mountable enclosure that can contain up to three transmitting and three receiving units.

The DDU will accommodate synchronous, asynchronous, and isochronous users as discussed below.

(1) Synchronous. The DDU will accept all rates specified in Table VI with synchronous interfaces. The DTE and the DDU must be timed by a common clock since the DDU does not have a buffer to compensate for clock differences. The DDU will provide counterdirectional or accept codirectional clock from the DTE or another external source. In the access area, the transmit clock will be looped from the received signal, which is slaved to the serving TCF, and provided to the DTE as shown in Figure 1. When the DDU is used to interconnect the earth terminal to the TCF, the co-directional clock mode will be used so that the buffer will not be required at the ET.

(2) Asynchronous. The DDU will accept asynchronous signals at the standard 75 x 2^N rates of 75 b/s to 2400 b/s. Asynchronous signals are oversampled and transmitted as synchronous signals. At present, the equipment description is not sufficiently detailed to determine how this is implemented, but there is concern over the isochronous distortion that could be introduced.

(3) Isochronous. The DDU procurement specification does not specify that the DDU will handle isochronous signals. Given that the above description on how the DDU accommodates asynchronous is correct, however, it can be concluded that the DDU will also accommodate nonstandard asynchronous rates and isochronous data circuits up to 2400 b/s. As mentioned above, there is concern about the digital distortion that will be introduced.

b. AN/FCC-100(V) Low Speed Time Division Multiplexer (LSTDM). The LSTDM [13] is a microprocessor implemented, full duplex multiplexer/demultiplexer that is designed to interface with a wide variety of user terminals. The principal applications of the LSTDM are to provide subscriber DCE ports for the DTN at the serving nodal locations and to multiplex up to 16 of these circuits into a data trunks for transmission over the available transmission facilities. The principal location of the LSTDM will be at the transmission node, but it may also be located in the subscriber access area to multiplex user channels for more efficient use of access area cable facilities. Within the transmission node, connections will be made using NRZ data and clock lines. For access area purposes, the DTN will use one of the following techniques to drive the access area cable facilities: the LSTDM internal conditioned diphase (CD) line driver, a separate synchronous line driver, or a separate synchronous VF modem. If all user circuits are intended for a common destination (either the user location or a point where circuits will be dropped and/or inserted), the CD data trunk can be used as an input port signal to LSTDM's at the serving nodal facility. The LSTDM can also be "nested", as shown in the remote access area in Figure 5, to extend the number

TABLE VI. DIGITAL DISTRIBUTION UNIT DATA RATE AND INTERFACE CHARACTERISTICS

Rate (b/s)	Non-Rtn to Zero	Mod Rate (Hz)	Synchronous	Asynchronous	Distance (Miles) (19 AWG Cable)
75	X	2400	X	X	23
150	X	2400	X	X	23
300	X	2400	X	X	23
600	X	2400	X	X	23
1200	X	2400	X	X	23
2400	X	2400	X	X	23
4800	X	4800	X		15
8000	X		X		
7200	X	7200	X		12
9600	X	9600	X		9
16 k	X		X		*
19.2 k	X	19.2 k	X		6
32 k	X		X		*
50 k	X		X		
56 k	X		X		
64 K	X		X		

* Capability is not known

of ports available such that more than 16 user data circuits can be accommodated. The LSTDM can be configured from controls on the front panel or from any ASCII terminal. The control terminal may be collocated or remote from the LSTDM. The control terminal interface is unbalanced NRZ at 110, 300, 1200 or 2400 b/s.

The port and aggregate rates, timing modes and electrical characteristics are shown in Table VII. The LSTDM will accept as many as 16 user data signals. These data signals can be multiplexed into an aggregate combined data trunk at transmission rates of 1.2 to 256 kb/s, as indicated. Port data are multiplexed onto the aggregate data trunk in 8 bit bytes. The LSTDM will accommodate synchronous, asynchronous and isochronous data circuits and also provides a VF channel capability. The VF capability has been included to implement voice orderwires for the DTN and for the digital radio service channel multiplexer applications.

Under most circumstances, the aggregate data trunk rate is a simple summation of the port rates plus a small amount for overhead required for frame synchronization. There are, however, configurations where the selected port rates require expanded aggregate capacity. This occurs for certain trunk and port configurations and whenever an isochronous port is used.

TABLE VII. LSTOM INTERFACE CHARACTERISTICS

PORT CHANNELS

Rate	Electrical Characteristics		Data Ports			VF Ports	
b/s	Conditioned Diphase	Non-Rtn-to-Zero	SYN	ASYN*	ISOC**	PCM	CVSD
<35		X					
37.5		X					
45.45		X					
50.0		X		X			
56.8		X					
61.12		X					
74.2		X					
75.0	X	X	X	X			
110.0		X		X			
135.5		X		X			
150.	X	X	X	X			
300.	X	X	X	X			
600.	X	X	X	X			
1.2k	X	X	X	X			
1.8k		X		X			
2.0k		X		X			
2.4k	X	X	X	X			
3.6k		X		X			
4.8k	X	X	X	X			
7.2k	X	X	X	X			
8.0k	X	X	X				
9.6k	X	X	X	X			
16k	X	X	X				X
19.2k	X	X	X	X			
32k	X	X	X				X
64k	X	X	X			X	X

AGGREGATE (DATA TRUNK) CHANNEL

Rate b/s	Conditioned Diphase	Non-Rtn-to-Zero	SYN
1.2k	X	X	X
2.4k	X	X	X
4.8k	X	X	X
9.6k		X	X
16k	X	X	X
32k	X	X	X
50k	X	X	X
56k	X	X	X
64k	X	X	X
128k		X	X
192k		X	X
256k		X	X

* Asynchronous user signals are accommodated at the specific rates indicated. The user signal can have 5, 6, 7, or 8, (including parity) data bits, 1 start bi and 1 or 2 stop bits.

** Isochronous user signals at any rate ≤ 2400 b/s are accommodated using transit coding.

Table VIII provides the LSTDM framing overhead and port rate multipliers required to calculate the aggregate rates for all possible configurations. Most multipliers are unity, but all multipliers for Isochronous ports are at least 4. The Isochronous port multiplier is the product of 4 times the multiplier for the synchronous port rate that it is transitionally encoded into. Except as indicated in note 2 of the table, all multipliers for asynchronous ports are the same as for the synchronous port of the same rate. In those application, where the transmission inefficiency becomes a problem, it is recommended that a nested LSTDM, with aggregate rates of 16, 4.8, 2.4 or 1.2 kb/s be used.

Synchronous, asynchronous or isochronous data circuits and VF circuits interface the LSTDM through port modules. Synchronous data circuits at the rates indicated in Table VII will interface electrically either with NRZ data and clock or with Conditioned Diphase (CD) signal. The LSTDM has 6 different port modules. Removal of unused or failed port modules from an operational LSTDM neither interrupts the operation of the remaining ports nor affects the trunk channel output rate. Circuits for which a particular LSTDM has been previously programmed can be added or dropped without interruption. Any other configuration changes will require reprogramming and, most likely, frame structure changes which will require the disruption of the trunk channel and therefore the disruption of all circuits being multiplexed. The port modules are described as follows:

(1) Synchronous. The synchronous LSTDM port modules will accept or provide either codirectional or counterdirectional clock signal. The receive clock signal is always codirectional. The input and output of the synchronous port module has a 32 bit first-in-first-out (FIFO) buffer that accommodates the clock difference for plesiochronous interfaces (codirectional transmit clocks). The buffer is normally set at a readout location such that the buffer will maintain BCI for at least 24 hours for port rates up to 32 kb/s if the clocks are accurate to within 1 part in 10^9. If this buffer underflows or overflows, it is automatically reset to its normal position. When a counterdirectional transmit clock is provided, the buffer will operate at its normal position. The synchronous port module provides a balanced or unbalanced (strapable) interface.

(2) Conditioned Diphase. The LSTDM Conditioned Diphase (CD) port module is basically a synchronous interface, but it provides a TRI-TAC compatible conditioned diphase, electrical interface. Since a CD signal provides both data and clock in a common signal, the clock signal is always codirectional. The CD signal is always balanced and has the capability of driving a greater distance than the NRZ electrical interface.

(3) Asynchronous. The LSTDM asynchronous port module will accept character encoded start-stop digital signals at the rates indicated in Table VII. The data characters can contain 5, 6, 7 or 8 data bits (including parity), 1 bit interval start pulse and a stop pulse of 1.0 or 2.0 bit interval. This port module will provide and accept only data signals (no clock signal) that is NRZ balanced or unbalanced. The asynchronous port module is implemented using a Universal Asynchronous Receiver Transmitter

TABLE VIII
LSTDM PORT RATE MULTIPLIERS TO CALCULATE AGGREGATE RATES

AGGREGATE RATE(b/s)	1200			2400			4800			9600			16K			32K		
FRAMING OVERHEAD(b)	50			100			200			400			200			400		
PORT RATE(b/s)	S	A	I	S	A	I	S	A	I	S	A	I	S	A	I	S	A	I
75	1	1	4	1	1	4	1	1	4	2	2	4	1	1	4	2	2	4
150	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4
300	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4
600	1	1	-	1	1	-	1	1	4	1	1	4	1	1	4	1	1	4
1200	-	-	-	1	1	-	1	1	-	1	1	4	1	1	4	1	1	4
2400	-	-	-	-	-	-	1	1	-	1	1	-	1	1	4	1	1	4
4800	-	-	-	-	-	-	-	-	-	1	1	-	1	1	-	1	1	-
7200	-	-	-	-	-	-	-	-	-	1	1	-	1	1	-	1	1	-
8000	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	1	-	-
9600	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	1	-
16K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
19.2K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-
32K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
64K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

AGGREGATE RATE(b/s)	50K			56K			64K			128K			192K			256K		
FRAMING OVERHEAD(b)	800			800			800			1600			1600			3200		
PORT RATE(b/s)	S	A	I	S	A	I	S	A	I	S	A	I	S	A	I	S	A	I
75	4	4	4	4	4	4	4	4	4	8	8	8	16	16	16	16	16	16
150	2	2	4	2	2	4	2	2	4	4	4	4	8	8	8	8	8	8
300	1	1	4	1	1	4	1	1	4	2	2	4	4	4	4	4	4	4
600	1	1	4	1	1	4	1	1	4	1	1	4	2	2	4	2	2	4
1200	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4
2400	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4
4800	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-
7200	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-
8000	1	1	-	1	-	-	1	-	-	1	-	-	1	-	-	1	-	-
9600	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-
16K	1	1	-	1	-	-	1	-	-	1	-	-	1	-	-	1	-	-
19.2K	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-	1	1	-
32K	1	1	-	1	-	-	1	-	-	1	-	-	1	1	-	1	-	-
64K	-	-	-	-	-	-	-	-	-	1	-	-	1	1	-	1	-	-

NOTE: 1. For Isochronous ports at rates not listed, the Isochronous port rate listed that is equal to or greater than the actual rate should be used.
2. For the asynchronous port rate of 50 b/s use 75 b/s, 110 b/s and 134.5 b/s use 150 b/s, 1800 b/s and 2000 b/s use 2400 b/s, and 3600 b/s use 4800 b/s.

S Synchronous
A Asynchronous
I Isochronous
- Not allowed

(UART). The UART digitally strips the stop pulses from the character and synchronously multiplexes the remaining data on the aggregate data trunk group. At the demultiplexer, the stop pulses are reinserted and the data is clocked out to the user. The advantage of this approach is that it provides a very efficient channel; however the port is limited to the specific character format for which it was configured. It is noted, however, that some asynchronous rates are multiplexed on the trunk group at the next higher synchronous rate and thereby have reduced rate efficiency. The port rate of 50 b/s uses 75 b/s, 110 b/s and 134.5 b/s uses 150 b/s, 1800 b/s and 2000 b/s uses 2400 b/s, and 3600 b/s uses 4800 b/s.

(4) Isochronous. The LSTDM Isochronous port module will accept either isochronous or asynchronous data signals at the data rates indicated in Table VII. The isochronous port module is implemented using transitional encoding and thereby provides a channel transparent to changes in rate or for asynchronous circuits changes in character code format. As in the case for the asynchronous port module, the isochronous port module will provide and accept only NRZ data signals (no clock signal) that is strapable, balanced or unbalanced. The isochronous port module will accept data at rates up to 2400 b/s in 6 ranges; $\leq$2400 b/s, $\leq$1200 b/s, $\leq$600 b/s, $\leq$300 b/s, $\leq$150 b/s and $\leq$75 b/s. As long as the user data rate does not exceed the rate range selected, the transitional encoding process will introduce no more than 10% isochronous distortion. The data is encoded at a synchronous, rate four times the upper bound of rate range selected. For example, the user's data is transitionally encoded into a synchronous rate of 300 b/s for the $\leq$75 b/s range and 9600 b/s for the $\leq$2400 b/s range. To minimize the accumulation of isochronous distortion on circuits that traverse multiple data trunks, tandeming is accomplished at the encoded synchronous rate using a synchronous port module.

(5) VF Port Module. There are two LSTDM VF port modules; one implemented using PCM at 64 kb/s and the other using CVSD at 16, 32 or 64 kb/s. The port module that should be used will depend on the particular application. In those cases requiring a high quality VF channel over several tandem links or where the intent is to transmit quasi-analog data (VF modems, DTMF signaling, etc.) the 64 kb/s PCM port module should be used. In those applications where the transmission capacity is limited, the CVSD port module should be used at 16 kb/s or 32 kb/s. There are no limitations on the number of VF port modules used except the available aggregate channel capacity.

The LSTDM multiplexer has two clock modes: internal clock and external clock. The internal clock accuracy and stability keep the output rate from deviating from the specific trunk rates by more than $\pm$ 3 parts in 10^6. The LSTDM will also operate from an external clock source at the trunk rate. Should the external clock signal be lost, the LSTDM will automatically switch to the internal oscillator. When the external clock is restored, the multiplexer will switch back to the external clock without manual intervention.

The aggregate interface can be either CD or NRZ at the rates indicated in Table VII. The selection between CD or NRZ is made by using the

appropriate Data Trunk aggregate card. The CD output is always balanced while the NRZ aggregate card is strapable balanced or unbalanced.

The LSTDM provides a data buffer for the received aggregate signal. The purpose of the buffer is to compensate for satellite delay variation, clock differences, or reducing digital distortion from received signals. The buffer length is selectable as 0, 1, 4, 8, 16, 32, 64 or 128 bytes. Each byte is 8 bits long; therefore the longest buffer length is $\pm$ 1024 bits. The buffer is adequate to compensate for satellite delay variations of 10 ms and station clocks with an accuracy of 1 part in 10^9 when operating at an aggregate rate of 64 kb/s or less.

The demultiplexer is provided clock along with the received trunk data signal. When the demultiplexer is operating in the NRZ mode, the associated clock is provided by the data source. When the demultiplexer is operating in the CD mode, the operation is basically the same except that the internal demodulator extracts clock and data from the CD signal and presents them to the demultiplexer in a NRZ format. The demultiplexer provides the received clock as an output. The demultiplexed synchronous port channels are clocked by the received clock and therefore will exhibit the same accuracy, stability and distortion as the received clock or the station clock if the data buffer is used.

When the LSTDM is used in a remote location where there is no station clock or other suitable external timing source, it operates in a looped clock mode using the received demultiplexer clock output as an external clock for the multiplexer.

2. CHANNELIZATION

The Government-owned portion of the DTN is a hierarchical system defined by three levels of time division multiplexing. These multiplexers provide digital channels through the network via available transmission media. Figure 8 illustrates the channelization scheme used for the DTN. The transmission DCE which provides user circuits entrance to the DTN must be configured to the user data circuit rate. In general, low speed user data circuits will access the LSTDM, which then enters a 56 or 64 kb/s data port of the AN/FCC-98. For future applications, medium speed user data circuits that are selected rates from the standard 56 to 512 kb/s will access the AN/FCC-98 (first level multiplexer), and user data circuits that are at the digroup (1.544 Mb/s) or higher rate will access the AN/FCC-99 (second level multiplexer).

The recommended channelization method for accommodating low speed data circuits in the DTN is to digitally multiplex these circuits into data trunks for transmission through the network. A data trunk will traverse the transmission facilities between the point where the individual data circuits are multiplexed into one data stream, to an equivalent end point where that data stream is demultiplexed into its constituent individual data circuits. This data trunk will typically be a 56 or 64 kb/s data channel between a pair of LSTDM's.

Through Routing

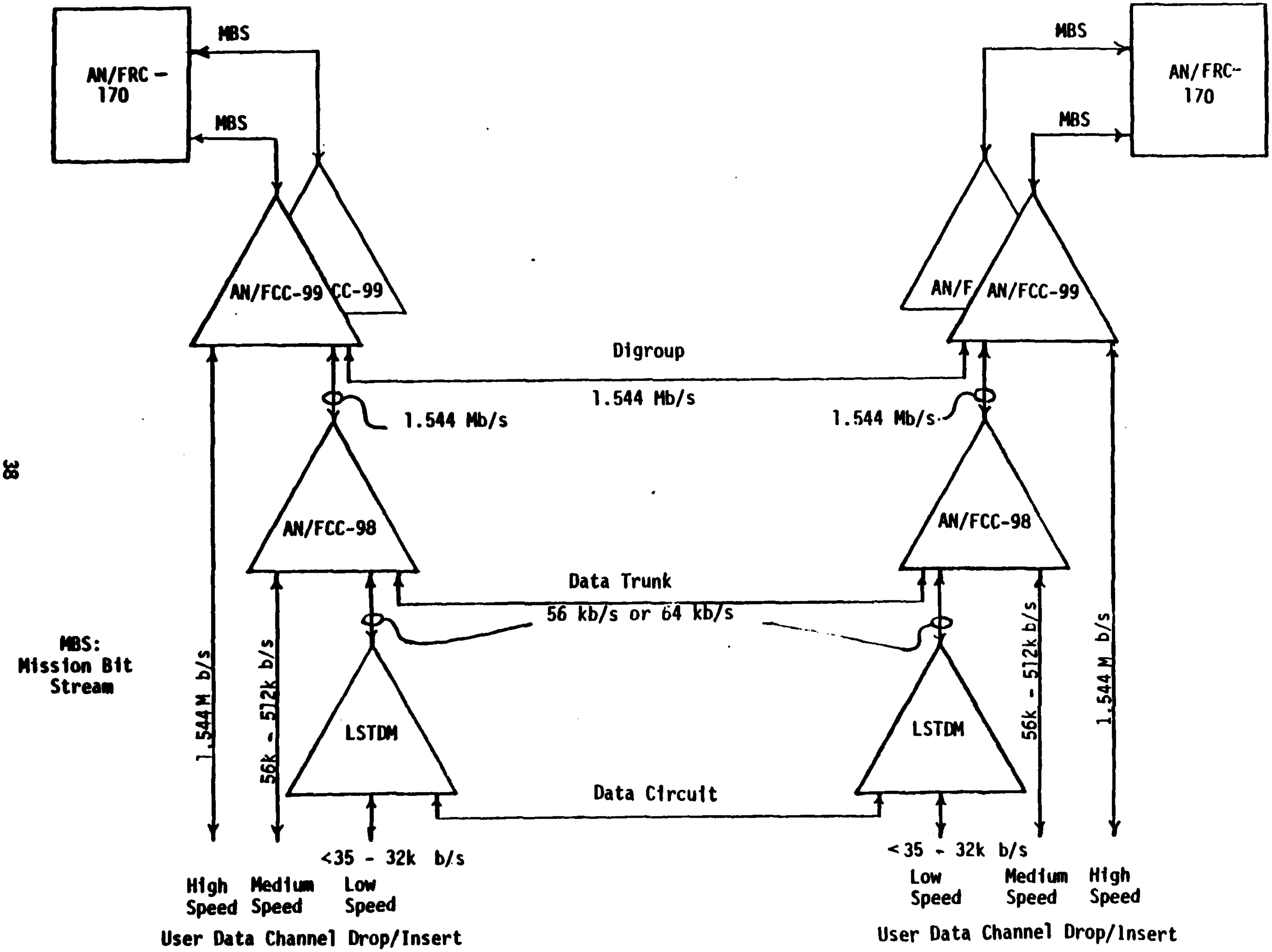


Figure 8. DTN Terrestrial Segment Channelization

Data trunks can traverse one transmission link to the next transmission node, or the data trunks can be routed through a number of nodes over a wide variety of transmission facilities to the TCF where the data trunk is terminated. For example, the FYP 83 network design has a data trunk that has 34 LOS microwave links and 5 troposcatter links in tandem. At the intermediate transmission nodes the data trunk is through-routed by connecting the higher speed data ports of appropriate multiplexers back-to-back. As shown in Figure 8, through-routing can be accomplished at the digroup (1.544 Mb/s) or the data trunk level. Through routing at the Mission Bit Stream (MBS) is not allowable since insufficient buffering is provided to maintain BCI. The performance of a data trunk is maximized when through-routing is accomplished at the highest level, since it minimizes the number of equipments that are connected in tandem. It is recommended therefore that where sufficient (or unique performance) circuit requirements exist between distant geographical areas, the data trunk for these circuits be established over the minimum number of tandem digroups.

Even though Figure 8 emphasizes the use of the DCS digital transmission facilities, other transmission facilities and data trunk rates are also possible. Exceptions to using the 56 or 64 kb/s rate should be made on a case-by-case basis, and will depend on the capacity required and the transmission facilities available. For example, where only analog VF circuits are available or to satisfy special survivability requirements, data trunks at rates of 2.4, 4.8, or 9.6 kb/s may be selected. These transmission rates will provide a highly survivable service in the sense that they can be readily restored over VF channels.

3. NETWORK SYNCHRONIZATION

The DTN is a synchronous network and each DTN node must be provided (or slaved to) a station clock. In the 1980-1990 time frame, the DCS will use two network synchronization techniques for providing station clock reference signals. The first can best be referred to as a slaved network synchronization approach since most DCS facilities will be slaved to the Cesium clocks at the U.S. Navy Observatory via the Loran C Navigational System. The second technique can best be called a plesiochronous (nearly synchronous) network synchronization approach where all nodes are provided independent and highly accurate station clocks. The DCS is designed to use the plesiochronous approach as a fall-back capability in the event that the Loran C derived station clocks are lost at one or more transmission nodes. Actually, the normal operation of the system will be a combination of the two approaches since some transmission nodes associated with DSCS facilities will use the earth terminal (ET) Cesium clock as a nodal station clock source.

All transmitted internodal digital signals (at least up through the 1.544 Mb/s first level multiplexer output) are transmitted in synchronism with the station clock. It is emphasized that the DTN can be synchronous without requiring the higher level multiplexers (second level multiplexer and multiplexers within the digital radio) to operate synchronously; however, there are performance advantages to operating the higher level multiplexer

synchronously. The following paragraphs address the basic ground rules for the synchronous operation of the DTN.

Synchronous user signals accessing the DTN for transmission should be slaved to the network using counterdirectional clock at the DTE-DCE interface. Exceptions to this are user terminals that interface with pulse stuffing DCE's and those that provide highly accurate (10^{-12}) clocks and interface DCE's with built-in data buffers. Examples of the DCE's that accept non-slaved synchronous users circuits by using pulse stuffing techniques are the AN/GSC-24 and Adaptive Multiplexer (AM) used over DSCS facilities, the 50 kb/s ports provided by the AN/FCC-98 and TSEC/CY104A, and the 1.544 Mb/s ports provided by the AN/FCC-97 and AN/FCC-99 second level multiplexer. User terminals interfacing these equipments need not be slaved to the DTN network to be provided service, but the terminal source clock must still be within specified accuracy bounds (50 to 250 ppm) and the routing must be limited to equipments (pulse stuffers and modems) not requiring synchronous processing. Providing synchronous data service to users with terminals that have inaccurate codirectional source clocks is therefore not recommended because of the engineering and restoral problems created. This, of course, does not apply to synchronous user terminals whose data rates have accuracies equivalent to that provided by the network (e.g. a few parts in 10^{12}). These terminals can be provided data service via any of the DTE-DCE interfaces using pulse-stuffing or data buffering discussed in this report.

Asynchronous and Isochronous data circuits do not have to be slaved to the network. These circuits can both be accommodated by Isochronous port modules that transitionally encode the user's signal into a data stream that is synchronous with the network. The CY104A and AN/FCC-98 have 0-20 kb/s isochronous port modules and the AN/FCC-100(V) has a 0 - 2400 b/s port module. It is emphasized, however, that these DCE do not accept or provide clock signals and cannot be used on synchronous circuits without providing a means of recovering clock.

All received digital signals entering a DTN node from other nodes have clock accuracies and stabilities determined by the transmitting node clock. These received signals also exhibit the transmission delay variations introduced by the intervening link(s). Received digital signals will either be dropped at a particular node or through-routed. Through-routing can be accomplished at the user rate, or the data trunk or digroup levels. Through-routed circuits that are to be transmitted from the node via synchronous transmission equipment must be brought into synchronization with the local station clock. Synchronization is accomplished using data buffers. These data buffers are either built into the transmission equipment or, in the case of satellite links, a separate stand-alone buffer can be used. Received data circuits that are dropped at the node are interfaced with the terminal equipment without further buffering for network synchronization purposes.

The following paragraphs describe the station clock, clock distribution subsystem and data buffers used to implement the system.

a. Station Clock. A functional diagram of the station clock and the clock distribution subsystem is shown in Figure 9. The system allows for two possible approaches for providing accurate station clocks: Loran C, or other highly accurate external reference sources such as an atomic clock. For terrestrial nodes collocated with DSCS sites, existing cesium beam standards used in the DSCS may be used as the reference for the DCS station clock. Two quartz crystal frequency standards are provided as back-up to ensure frequency stability for the periods when the Loran C or external reference sources are not available. These oscillators, locked to a reference, will have an initial accuracy equal to the reference and a long term stability of 1×10^{-9}. For non-DSCS sites, Loran C will be used as the primary reference source for the station clock. Both the DSCS atomic clocks and the Loran C navigational system have transmit frequency sources that are synchronized to Coordinated Universal Time (UTC). UTC has a rate accuracy no worse than $\pm 1 \times 10^{-12}$. To the extent that DCS clocks will be slaved to the UTC the DCS will be a slaved synchronous network.

The implementation of the network does not require that every node have a Loran C receiver or Cesium beam atomic clock. An allowable implementation would be to provide these primary clock sources at major nodes, with minor nodes slaved to them. The decision as to which nodes are major and minor is an engineering consideration to be made on a case by case basis. [10]

The clock distribution subsystem interfaces with the station clock to generate and distribute timing signals to transmission and user equipments. In order to meet DCS availability criteria, triple redundant frequency synthesis, followed by majority vote logic, is provided. Voting logic will select one of the three frequency synthesized outputs and provide the selected frequency rate to the distribution amplifier. The distribution amplifier then provides an individually isolated output to each equipment as required.

b. Buffers. The network synchronization system cannot be considered truly synchronous in that the network nodes are not always slaved to a single common timing source. Even if they are, some data buffers are required to account for delay variations of the transmission media. The most critical buffer design requirement, however, is to accommodate the plesiochronous mode of operation. In a plesiochronous system, data and transmission system digital signals generated under the control of one station clock may be at a slightly different rate from those generated under the control of other station clocks within the network. To maintain Bit Count Integrity (BCI), buffers are used to compensate for the phase difference between these signals. Buffers are required also to compensate for small timing differences which may arise because of differences and perturbation in Loran C transmission. By design, internal buffers have been included as an integral part of most of the input circuits for the digital equipment used to implement the DTN. The equipment input buffers have been designed to provide BCI for 24 hours in a plesiochronous system when the station clock stability is 10^{-9}. In a plesiochronous system that has station clocks of 10^{-11}, BCI theoretically would be extended to 2400 hours. For those stations slaved to a single clock

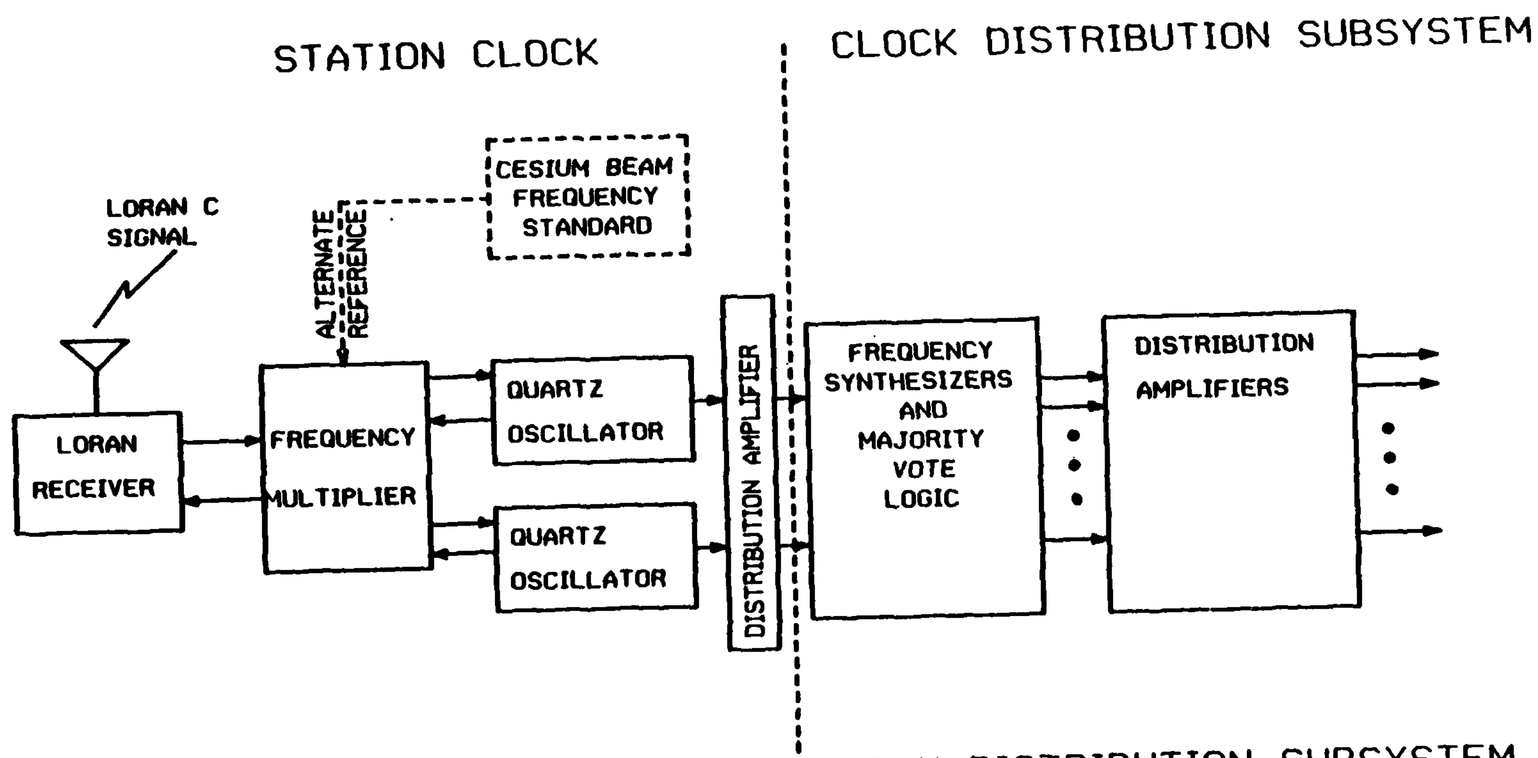


FIGURE 9. DCS STATION CLOCK AND CLOCK DISTRIBUTION SUBSYSTEM

or coordinated with UTC, BCI will be maintained for an indefinite period of time. Noted, however, that buffer sizing is critical in that if a buffer reaches an under-or overflow condition, it will reset to its midpoint, causing a loss of BCI.

For circuits traversing satellite paths, an additional buffer is required to compensate for relatively large path delay variations. Satellite paths experience delay variations that are caused largely by satellite orbit inclination, orbit eccentricity, and atmospheric/ionospheric variations [10]. The satellite is initially orbited with a maximum tilt in one direction and during the satellite operational lifetime the orbital plane tilt shifts through 0° and then in the opposite direction. The path length delay variation due to orbital tilt varies with the tilt angle and ranges from 1 to 4 ms. The delay variation is largest at the beginning and end of the satellite operational lifetime and is minimum during mid-life. The path delay variation is also a function of the orbital eccentricity, which is a daily variation. DSCS satellites are allowed a 1% eccentricity which contribute as much as 5.6 ms additional delay variation. Future DSCS satellites will be better controlled and thus reduce the orbit eccentricity delay contributions. Propagation delay due to atmospheric and ionospheric variations contributes an additional delay variation of approximately 1 ms. This results in a total maximum diurnal delay variation of approximately 10 ms. To compensate for this satellite path delay variation (doppler), a $\pm$ 10 ms stand-alone satellite buffer capability is required. With the buffer initially set at mid-position, the satellite buffer will essentially equalize the satellite path delay to 260 ms. The technical details of the satellite delay buffer are discussed in section IV,4,b,(1).

Since the number of bits of buffering required to compensate for the satellite path transmission delay variation is a function of data rate, a separate buffer is not always required. For example, since a much smaller buffer is required for low data rate circuits, it is possible to compensate for satellite delay variation in the output circuits of certain transmission equipment (e.g., the Adaptive Multiplexer (AM)). The AM along with its output buffer uses pulse stuffing to meet the specified slew rate distortion requirements. This internal buffer will also compensate for satellite delay for circuit rates up to approximately 6000 b/s. In the same way, the LSTDM buffer will compensate for satellite delay variations for aggregate rates up to 64 kb/s.

4. INTERNODAL TRANSMISSION FACILITIES

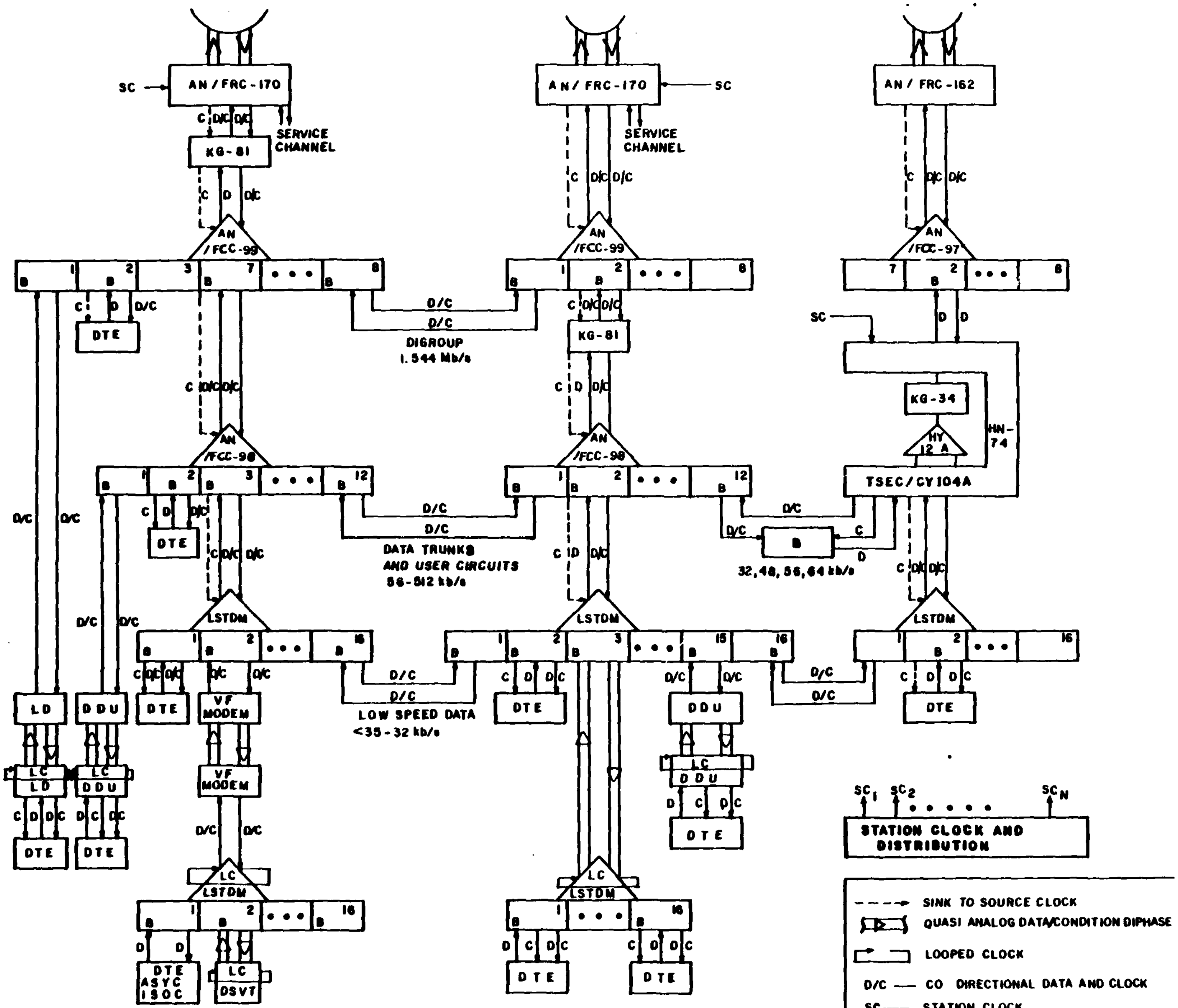
The transmission facilities that are to provide the telecommunications capability for the DTN include the terrestrial digital DCS, the Defense Satellite Communications System (DSCS), leased digital facilities, and Government-owned and leased analog facilities. Each of these major transmission subsystems will be discussed in more detail in the following paragraphs.

a. Terrestrial Digital. Figure 10 depicts the predominant internodal, Government-owned transmission facilities that will be used to implement the DTN. Digital channels are provided for the DTN by a three-level multiplex hierarchy. The LSTDM will be used as the DCE to interface with the low speed data circuits and to time division multiplex them into data trunks (usually at 56 or 64 kb/s). The data trunks and medium speed data users are provided digital channels by the AN/FCC-98 or the CY-104A (first level multiplexers) using the multirate synchronous data port module. These data channels are multiplexed into digroups (1.544 Mb/s) along with voice signals that have been digitized using pulse code modulation (PCM). These digroups are multiplexed by either the AN/FCC-99 or the AN/FCC-97 (second level multiplexers) into mission bit streams (MBS) at 3.232, 6.464, 9.696, or 12.928 Mb/s (AN/FCC-99) or 12.6 Mb/s (AN/FCC-97) for internodal transmission.

The AN/FCC-98 and AN/FCC-99 multiplexers and the AN/FRC-170 Series (V) digital radio are currently being used to upgrade and digitize oversea DCS analog transmission facilities. In this initial application the DCS digital transmission system does not operate synchronously. The AN/FCC-98 (first level PCM multiplexer) provides VF channels to replace equivalent analog FDM channels. The AN/FCC-99 (second level multiplexer) uses pulse stuffing to maintain bit synchronization between the first and second level multiplexers. With the implementation of the DTN using the synchronous LSTDM and the multirate digital data module in the synchronous AN/FCC-98 (first level multiplexer), the DTN portion of the transmission network will become synchronous. In higher levels of the network, the AN/FCC-99, using its pulse stuffing capability, will continue to operate non-synchronously during the early stages of DTN implementation. The AN/FCC-99 multiplexer also has the capability of operating synchronously and may be converted to the synchronous mode when the network timing system is implemented to provide improved network performance. This will eliminate pulse stuffing errors which cause loss of bit count integrity (BCI).

Figure 10 shows a generalized configuration of nodal equipment depicting how the mission bit streams, digroups, digital data groups, and low speed data circuits can be either dropped and inserted or through-routed at the appropriate level of the digital hierarchy. A digital circuit provided by the DTN and passing through the DCS digital transmission system will be processed at each node as illustrated in the figure. There are also repeater and branching repeater configurations where the mission bit stream is received, regenerated, and retransmitted. In a synchronous network, with accurate timing sources at each transmission node, these configurations are special cases of the one shown.

In the synchronous mode of operation, all transmitted signals from a DCS digital terrestrial facility are timed by the station clock that is slaved to Loran C, and thus in a normal mode of operation is without long-term frequency error. The encryption equipment and the multiplexing equipment are slaved, in turn, to the transmitter as shown by the dashed clock lines in Figure 10. Received signals at each digital level in the hierarchy are slaved



DIGITAL TRANSMISSION EQUIPMENT

to the source clocks at their originating nodes. Even though the station clocks at all nodes are coordinated, the system must be capable of operation using independent clocks in a fall-back mode. Therefore, data circuits that are through-routed at any level of the digital hierarchy must be phase compensated for transmission rate inaccuracy (between the local and remote station clocks) and for a small amount of transmission delay variation before they are remultiplexed for transmission to the next node. In the DCS terrestrial digital transmission network using DRAMA equipments, the received transmit signals (i.e., the input digital signal to the multiplexers) are synchronized to the local clock by data buffers (as indicated by the "B" at the input port in Figure 10). Table IX gives the buffer length and expected time that BCI will be maintained at that interface when operating in the fall-back mode.

Synchronous user circuits accessing the DTN must be slaved to the network clock. DTE's that can accept external clock will be provided their timing by the DCE via the station clock. An example of this is the accession by the DTE's of the first and second level multiplexers shown on the right side of Figure 10. User circuits accessing the network via line drivers, VF modems, group modems, or LSTDM's will be provided clock by looping the received signal of these devices at the remote site. The transmit digital input is normally provided by a counterdirectional timing signal. An exception to this is the KY-78 (DSVT) which has the capability of providing looped clock. The DSVT has a conditioned diphase interface, so a clock signal is not provided; therefore, looping the clock within the terminal is essential.

b. Digital Satellite. The use of a government-owned satellite (DSCS) is treated as a separate transmission facility, principally because of its unique characteristics and the capabilities to provide ECM protection for command and control users. The equipment configurations required by TCF's serving DSCS earth terminals are described in this section. The configuration shown in Figure 11 is typical of those facilities where the earth terminals and the serving TCF are separated by several miles and require a cable driving capability. When longer distances are encountered, terrestrial digital transmission facilities, as discussed in the previous section, would be used and, in effect, the TCF and the earth terminal would be collocated.

All synchronous circuits, data trunks, or user circuits received via a satellite link through a satellite TCF are shown with a satellite delay buffer to compensate for satellite transmission delay variations. The data buffer, because of lack of space at the ET, will be provided at the TCF serving the earth terminal. The data is clocked out of the buffer with the station clock so that the received data circuits are synchronized to the serving TCF and can be synchronously multiplexed at any level of the digital hierarchy. A ground rule that must be followed is that all circuits received over a satellite link must be buffered before being processed by a synchronous multiplexer.

TABLE IX. DCS DIGITAL TRANSMISSION EQUIPMENT
MINIMUM TIME TO LOSS OF BCI

	Transmission Rate (kb/s)	Buffer Length (bits)	Min BCI (hrs) 10^{-11} clocks
AN/FRC-170 (V) SERIES DIGITAL LOS RADIO	12,929	$\pm$ 11	12
	9,696		18
	6,464		24
	3,232		47
AN/FCC-99 SECOND LEVEL MULTIPLEXER	1,544	$\pm$ 8	72
AN/FCC-98 FIRST LEVEL MULTIPLEXER	512	$\pm$ 64	1736
	256		3472
	128		6944
	64		13889
	56		15873
AN/FCC-100(V) LSTDM SYNCHRONOUS PORTS	64	+6, -16	1519
	32		3038
	19.2	+4, -19	2893
	16.0	+3, -20	2604
	9.6	+2, -21	2893
	8.0		3472
	7.2		3858
	4.8	+1, -22	2893
	2.4		5787
	1.2		11574
	.6		23148
	.3		45296
	.150		92592
	.075		185185

Data circuits traversing a satellite link can be divided into two categories: ECCM and non-ECCM circuits. Only certain low rate data user circuits are provided ECM protection. Non-ECCM low rate user circuits will be sent to the DSCS earth terminal and multiplexed into standard data trunk groups of 56 or 64 kb/s by the LSTDM, as shown in Figure 11. Note that the LSDTM has a built-in data buffer capability for aggregate rates up to 64 kb/s. If higher aggregate rates are used the external buffer will be required. In general, the data trunks will traverse only a single satellite link. If the circuits extend beyond the serving TCF, they will be remultiplexed into other terrestrial or satellite data trunks. The data trunk medium and high speed data circuits will be multiplexed into a satellite link MBS by the AN/GSC-24. Care must be taken when interfacing with the AN/GSC-24, because of the slew rate distortion caused by pulse stuffing. The DDU/GSC-24 interface has been tested, and the LSTDM and the data buffer have been specified to interface with the AN/GSC-24. The KY-801 provides coding and decoding to improve the error performance of the DSCS satellite links. The MBS is routed through the KY-801 Encoder/Decoder. The KY-801 will improve the bit error rate (BER) but may also extend the transmission delay of DTN circuits, and therefore must be considered in the performance evaluation. The MBS is then applied to one of several possible satellite modems. The MD 1002 B/QPSK modem is shown, but the MD 921 could also be used.

Low speed ECCM circuits are transmitted to the earth terminal via the TCF as individual circuits. The reason for this configuration is that these circuits must interface directly with the AN/USC-28 or the adaptive multiplex ports. There is no plan to remote the AM to the serving TCF because it is under the control of satellite Real Time Adaptive Control System (RTACS). As the satellite link is subjected to increasingly greater jamming levels, the higher rate circuits are dropped by the AM, and the Burst Error Coder (BEC) and AN/USC-28 modem are modified to provide increased ECM protection.

(1) Data Buffers. Synchronous digital transmission networks must be designed to accommodate transmission rate differences at each synchronous interface. Transmission rate differences are not only caused by slight differences between the nodal facility station clocks at each, but also by variances in the effective length of the transmission path. To compensate for path delay variation and nodal clock difference, a satellite delay compensating buffer is required. The minimum satellite path delay is 240 ms and the maximum path delay is 250 ms. The buffer, in effect, equalizes the satellite delay to a constant value. If the buffer can be initialized in phase with the daily variation, the delay can be equalized (worst orbital case) to 250 ms. To avoid having to coordinate the phase of the buffer setting with the satellite delay variation, a ± 10 ms buffer is used. If the buffer is reset to its midpoint at maximum satellite path delay, the maximum equalized delay of the satellite links is 260 ms. Note that the equalized delay of the satellite link could be greater than 260 ms because the delay of the buffer portion of the circuit is a function of the buffer length in bits and the data rate of the circuit that is being equalized. To minimize the

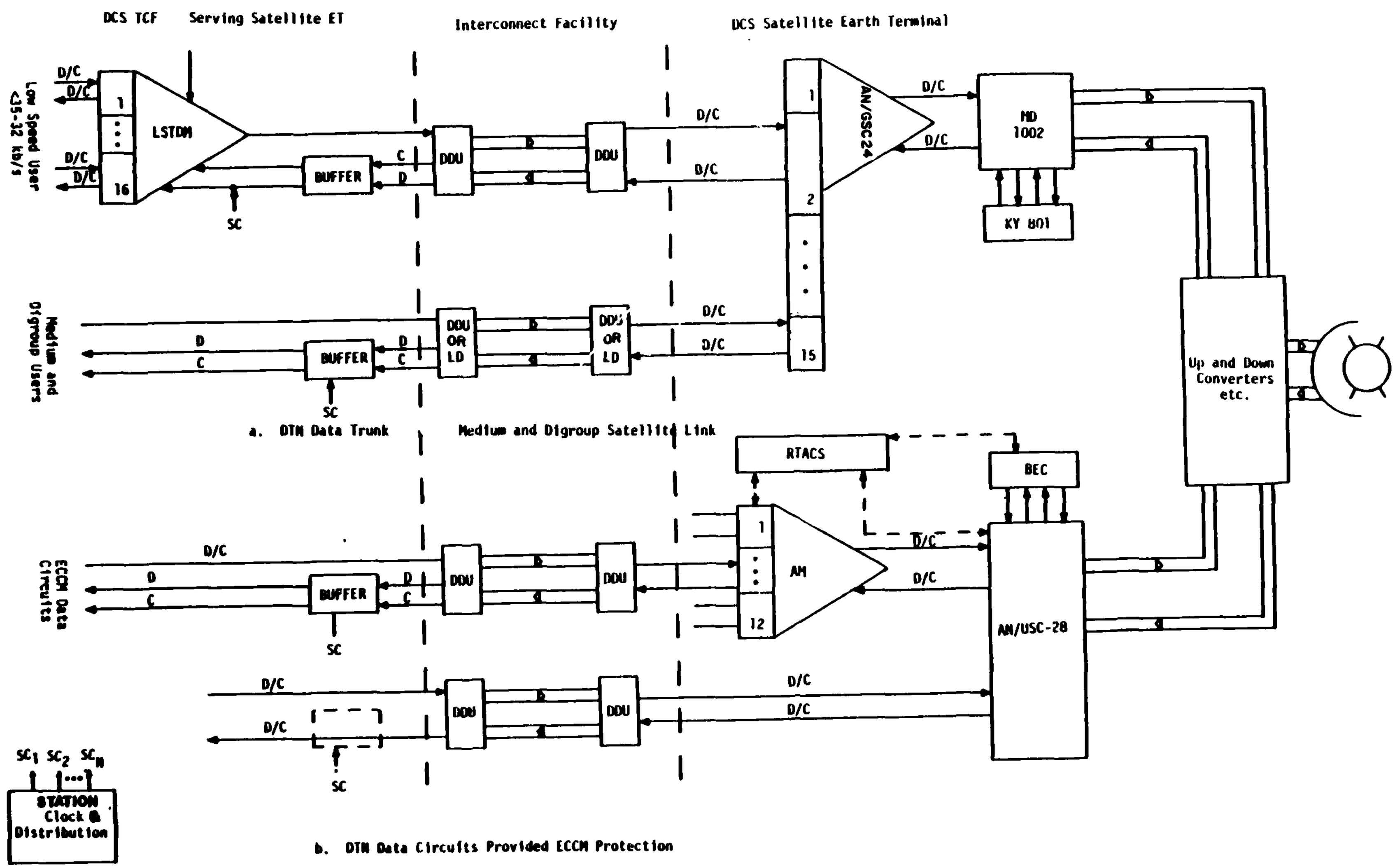


Figure 11. DTN/DSCS Interface Configuration

circuit delay associated with a satellite delay buffer, the buffer length, in bits, must be matched to the maximum delay compensation required in terms of path delay and clock difference for the specific rate that is operating. An incorrect buffer length will cause poor circuit performance due to loss of BCI or excessive delays.

The buffer is specified [14] to accommodate the worse case satellite path delay variations of $\pm$ 10 ms and clock source accuracies of 10^{-11} for transmission rates of up to 2.048 Mb/s. It performs this function by reading the input bit stream into the buffer with the phase varying input clock and reading the output bit stream with a local station clock. The buffer is specified to maintain BCI for 10 days when the input and output clocks differ by as much as 2 parts in 10^{10}. At 2.048 Mb/s, $\pm$ 354 bits of buffering are required to compensate for rate inaccuracies and $\pm$ 20,480 bits are required for $\pm$ 10 ms satellite delay. To meet the satellite requirements at 2.048 Mb/s and to minimize the delay for less severe requirements, the buffer is strap (or switch) selectable to the following buffer lengths: $\pm$ 32,768, $\pm$ 16,384, $\pm$ 8,192, $\pm$ 4,096, $\pm$ 2,048, $\pm$ 1,048, $\pm$ 512, $\pm$ 256, $\pm$ 128, $\pm$ 64, $\pm$ 32, $\pm$ 16, $\pm$ 8 or $\pm$ 4 bits. For any selected buffer length, the buffer fill will be reset to the center position automatically whenever buffer overflow or underflow occurs, or reset manually whenever the buffer reset button is operated.

(2) AN/GSC-24. The AN/GSC-24 TDM provides the means for multiplexing up to 15 digital data channels into a mission bit stream (MBS) for transmission over a satellite link. The multiplexer will accept codirectional synchronous input rates from 50 b/s to 3.0 Mb/s and provide a aggregate output rate of up to 10 Mb/s. The input channel rates do not have to be synchronous with the multiplexer clock, since the device will accommodate rate differences of up to 250 ppm by pulse stuffing. The pulse stuffing approach introduces slew rate distortion due to dropping and/or reinserting the stuff and spill bits. The slew rate [19] in the AN/GSC-24 is a function of the data circuit rate, and is pi radians in 500 bits at 1200 b/s and pi radians in 1500 bits at 9600 b/s. Since slew rate is not a common performance parameter and it is not specifically known how much slewing various equipments will tolerate, tests were run on some typical modems at SATCOMA in August 1979. The results of these tests indicated that these modems would accept no more than pi radians of phase change in 10,000 bits. The slew rate of the AN/GSC-24 at higher rates is less severe because of a narrowband smoothing loop. Tests must be conducted to determine the ability of the digital distribution unit to track the slew rate distortion at these higher rates. It is likely that this unit will simply pass the distortion to the next equipment. The LSTDM is specified to interface with the AN/GSC-24 at all port and aggregate rates but will be tested at rates of 1.2, 9.6, and 256 kb/s. Since the data circuits will have data buffers to compensate for satellite delay variation, the signals will be clocked out under the control of the station clock, and the output of the buffer will have all forms of digital distortion removed.

(3) Adaptive Multiplexer. The adaptive multiplexer (AM) is intended for use at DSCS earth terminal sites to multiplex/demultiplex synchronous, asynchronous, and isochronous low speed data circuits that will be provided ECCM protection via the AN/USC-28 modem. The AM will accept up to 24 simplex or 12 duplex data channels at rates from $\pm$ 35 b/s to 50 kb/s and multiplex (and demultiplex) them into a data group that can range from 75 b/s to 256 kb/s in steps of 12.5 b/s. Any changes in port timing mode or rates will not require modular replacement and the AM can be configured to the extent that specific port channels for which it is designed to accept can be added or dropped. When receiving a command to drop or add a channel, the AM will adjust the data group trunk rate to a minimum (allowing for up to 10% overhead). Having the adjustable and efficient data group rate allows maximum ECCM protection by the AN/USC-28 modem.

The AM accommodates synchronous data circuits by using pulse stuffing. The pulse stuffing technique is designed to accommodate data circuit rate inaccuracies of $\pm$ 250 ppm. The timing signal for the port module input is codirectional. This implies that the AM cannot be used to accommodate DTE's that will ultimately be serviced by plesiochronous synchronous interfaces in other portions of the network unless the DTE is provided an accurate clock source. The synchronous demultiplexer port module uses an 84 bit buffer and clock arrangement to hold slew rate to 1.0 radian in 1600 bits and/or .1 radian over 160 bits. The 84 bit buffer will introduce a maximum of 84 bits of delay for all synchronous circuits regardless of rate.

The AM will accept asynchronous data circuits at standard 75 x 2^N rates up to 150 b/s with start-stop digital signals whose characters contain 5, 6, 7 or 8 data bits and with stop pulse widths of 1.0, 1.42, 1.5 or 2.0. These channels will be processed using one of two selectable options. In the first option, the character oriented words received will be stripped of the start or stop pulses and the data will be synchronously multiplexed into the combined channels. This option will provide efficient utilization of the data trunk capacity. The second option will use a transitional encoding technique, which will provide a more transparent channel when data trunk efficiency is not important.

The AM will accommodate isochronous channels at any bit rate up to 600 b/s and will be implemented using transitional encoding. The data trunk rate allocated for each isochronous port channel will not exceed four times the port channel rate. For isochronous rates less than 75 b/s, however, the data trunk rate is limited to only 300 b/s. The AM also accommodates the input channel rate of 50 kb/s. The DTE source of these signals is the KY-3 which neither provides a clock signal nor accepts external clock. The KY-3 signal, therefore, falls within the definition of an isochronous data signal. The current specification indicates that these circuits will be accommodated by using pulse stuffing.

c. Analog FDM. Standard analog FDM VF (.3 to 3 kHz) and group channels (60-108 kHz) can be provided worldwide over both Government-owned and leased transmission facilities. Where digital transmission facilities are not

available or where special performance characteristics are required, VF and group modems will be used to provide digital channels. The AN/GSC-36 group data modem (GDM) will provide digital channels at 56, 64, 112, or 128 kb/s. Most commercial synchronous VF modems that operate at rates of 1.2 to 9600 b/s can be used. For special applications, the AN/GSC-38 modem can be used to provide 16 kb/s channels.

Figure 12 represents several typical equipment configurations where data circuits traverse leased or Government-owned FDM transmission facilities. Station clock will typically not be available at these sites. For these equipment configurations, the received clock at the remote TCF will be looped, to provide transmit timing at the remote site. The AN/GSC-36 GDM and the LSTDM have the capability of looping received clock. For the example shown, the time could have been looped at the LSTDM or the GDM. It is emphasized that any VF modem or line driver selected for the DTN must have the capability of looping received clock for use as transmit clock.

The design of the AN/GSC-38 16 kb/s VF modem provides excellent synchronization performance, but does not provide the capability for looped clock. The received signal is demodulated using local clock rather than received clock. Received clock is not detected and therefore cannot be looped. For this reason, care must be exercised in using the AN/GSC-38 modem in data applications.

On the DTN node side of the FDM link, transmit clock is provided by the station clock for those devices that have input data buffers. For the low speed data circuits using LSTDM's, the clock is provided by the LSTDM. The LSTDM transmit clock is then the transmit clock for the modem. At the remote site, this transmit clock becomes the received clock and is looped back as discussed in a preceding paragraph. The AN/GSC-36 GDM has no input data buffer and therefore must use the clock associated with the input transmit data as transmit clock. The clock is looped at the remote site and will be buffered at the DTN node. For example, if the AN/GSC-36 GDM is used to extend a 56 kb/s user circuit that is an output of an AN/FCC-98, the $\pm$ 64 bit buffer on the data module will buffer out any phase delay variation that may have accumulated on the FDM link.

d. Leased Facilities. Currently, there is a proliferation of commercial data transmission services being offered, both overseas and CONUS. Many of these leased commercial digital transmission facilities are currently available to support the DTN. This report addresses cnly two typical leased data transmission services, which will be considered for early DTN applications. The interface requirements for other leased data services should be addressed since their availability enhances the survivability of the DTN.

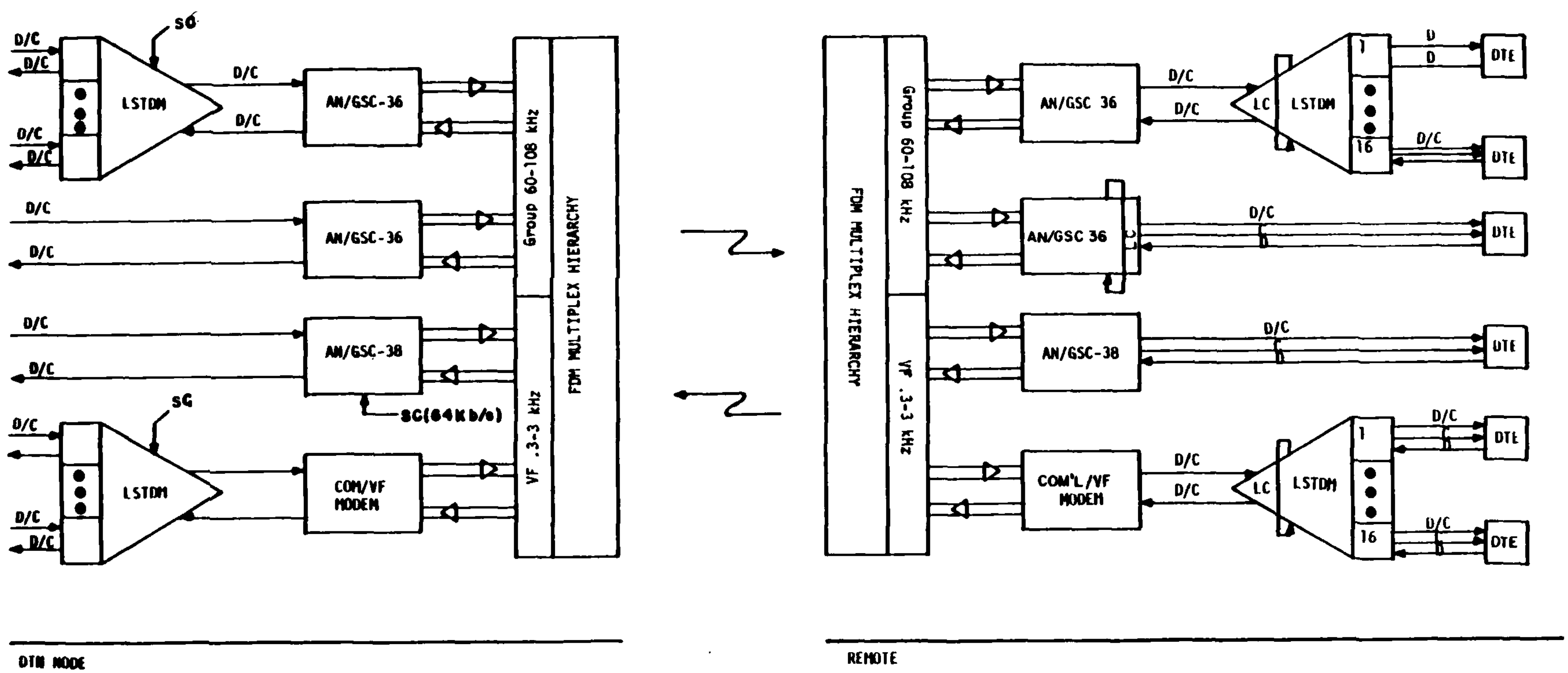


Figure 12. FDM Transmission Facilities

(1) Washington Area Wideband System (WAWS). The WAWS is a digital transmission network, designed to provide DCS digital transmission service among Government-owned facilities in Pennsylvania, Maryland, Virginia, and Washington, D.C. The 11 government sites that are interconnected by the WAWS are:

Blue Ridge Summit, Pennsylvania
Ft. Detrick, Maryland
Friendship, Maryland
Ft. Meade, Maryland
Naval Security Station (NSS) Washington, D.C.
Pentagon, Arlington, Virginia
Andrews AFB, Maryland
Ft. Belvoir, Virginia
Liberty Dam, Maryland (repeater site)
Damascus, Maryland (repeater site)
Tenly, Maryland (repeater site)

Figure 13 depicts a typical WAWS nodal equipment configuration as applied to the DTN. The repeater sites will provide only through-routed channels at the digroups and mission bit stream (MBS) levels. The LSTDM, the TSEC/CY-104A and AN/FCC-98 (first level multiplexers), the CV-3511/TD-1220 (second level multiplexers), and the KG-81's are provided by the Government. The 12.928 Mb/s digital trunks, provided to the DMX-A3 and DMX-C3 multiplexers, and the 90 Mb/s digital radio are leased from Western Union. This basic approach for providing upgraded digital transmission facilities is being planned for several other areas. At present, these areas include East Coast Wideband System (ECWS) interconnecting Washington D.C. area (WAWS) and Norfolk, Virginia (NAWS), Hawaii (HAWS) and California (CAWS). These other upgrades will be considered relative to the DTN when their planning is further developed. They are expected to have equipment configurations similar to the WAWS.

The WAWS digital radio has an output transmission rate of 90.258 Mb/s and operates in the common carrier band of 6 GHz and 11 GHz. The radio accepts two digital bit streams of 44.736 Mb/s and synchronously multiplexes them into a 90.258 Mb/s stream for internodal transmission. The WAWS radios are provided clock by the network clock and distribution system. The accuracy and method of distributing the clock are not significant since the next two levels of multiplexers are nonsynchronous pulse stuffers.

Figure 13 shows the next level multiplexer, below the radio, as the DMX-A3. The DMX-A3 is a pulse stuffing multiplexer designed to accept three 12.928 Mb/s data streams plus three 1.544 Mb/s data streams and multiplex them into one 44.736 Mb/s data stream and conversely, demultiplex the combined stream. The DMX-C3 is a pulse stuffing multiplexer designed to multiplex one 36.818 Mb/s and three 1.544 Mb/s data streams into a single 44.736 Mb/s data stream and also demultiplex the combined stream. The DMX-A3 and DMX-C3 receive clock from the 90 Mb/s digital radio.

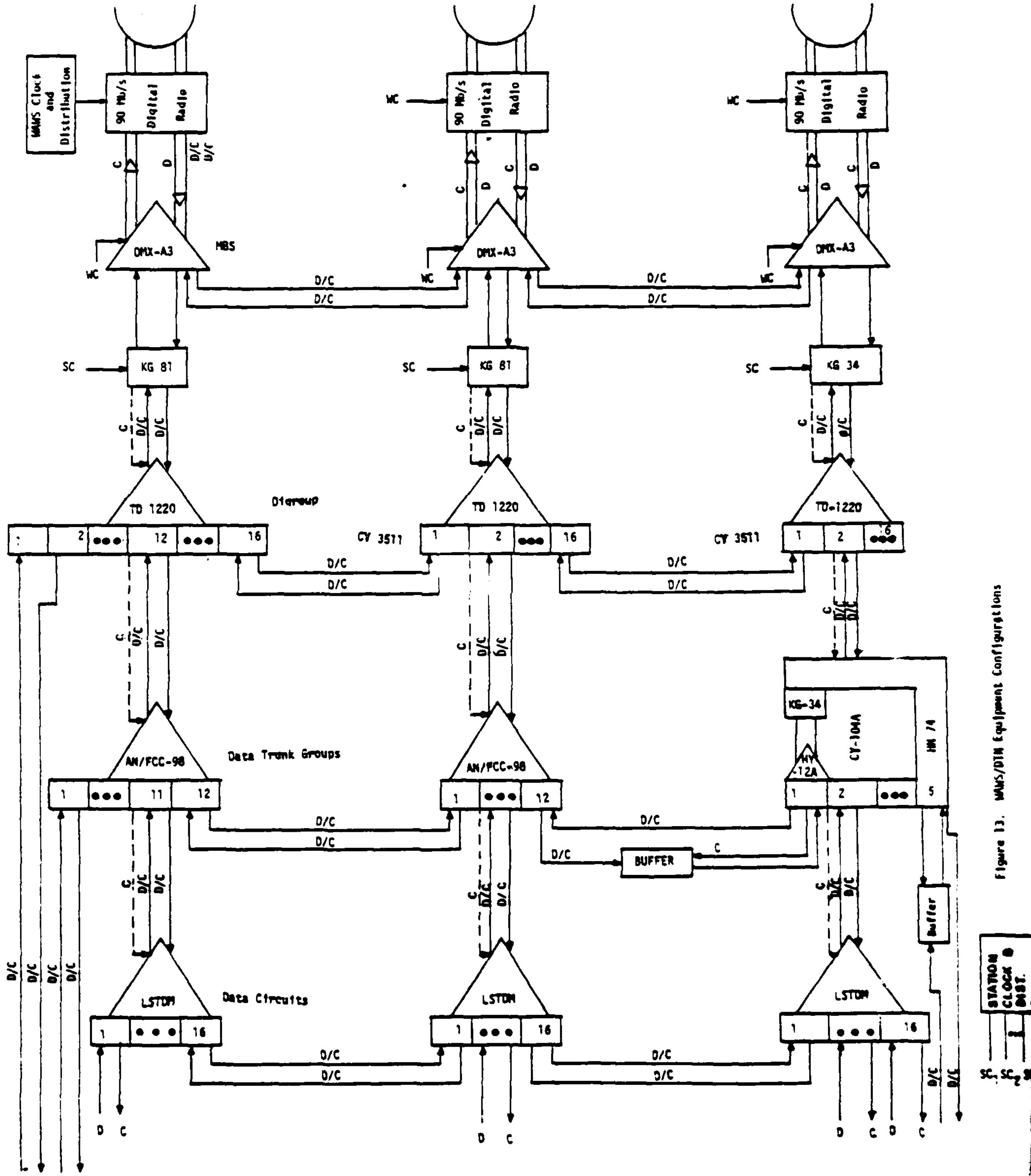


Figure 13. WAWS/DIN Equipment Configurations

The TD-1220 is a programmable synchronous multiplexer that can be programmed to accept up to 12 input data streams at a wide varietv of data rates. The CV-3511 is a pulse stuffing unit that will compensate for the port clock difference. When the TD-1220/CV-3511 combination is configured with program 20, ports 1 through 8 accept 1.544 Mb/s, port 9 accepts 16 kb/s, port 10 accepts 2.4 or 4.8 kb/s, and ports 11 and 12 are not used. The combined rate of the TD-1220 is the WAWS MBS and is always at 12.928 Mb/s. The TD-1220 accepts transmit clock from the higher level equipment as shown. MBS's can be through-routed as input and output ports of the DMX-A3 and DMX-C3.

The first level multiplexers are the AN/FCC-98 and the TSEC/CY-104A. These devices are PCM VF channel banks that are also equipped to accept data modules in place of VF channel modules. The synchronous data module will accept synchronous data trunks provided by the LSTDM.

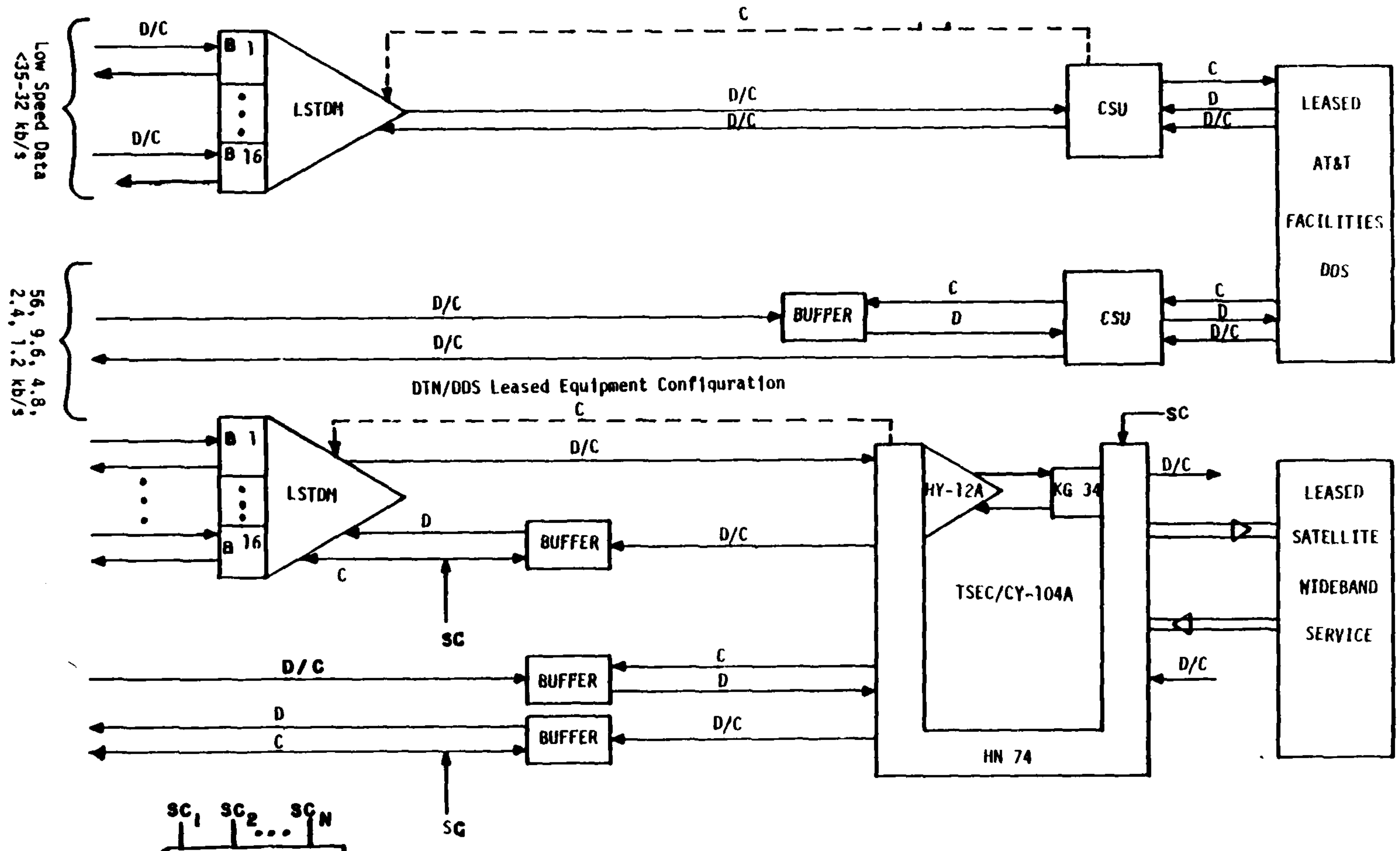
The CY-104A is an assemblage of equipment consisting of an HY-12 PCM channel bank, HN-74 controller/interface unit, and a KG-34 crypto unit. The HY-12 is a commercial VICOM D2 PCM VF channel bank housed in a shielded cabinet modified to provide NRZ data and timing to the KG-34. The HY-12 accepts up to 24 VF channels which are multiplexed into a 1.544 Mb/s digroup. In the HY-12A and the corresponding CY-104A, 5 of the 24 VF channel modules can be replaced with data modules. The data modules will provide ports for 0-20 kb/s isochronous or asynchronous, 50 kb/s isochronous, or 32, 48, 56, and 64 kb/s synchronous. The synchronous data module will normally be used to provide channels for the DTN. In contrast to the synchronous data module for the AN/FCC-98 (which provides a $\pm$ 64 bit buffer), the CY-104 data module only provides a $\pm$ 1 bit buffer. A $\pm$ 1 bit of buffer will maintain BCI for 24 hours for clock accuracies of $\pm 5 \times 10^{-11}$. For that reason, input transmit circuits need to be provided a separate data buffer, as shown, if worse clock accuracies are expected.

The WAWS is a nonsynchronous network since the DMX-A3 and TD-1220/CV-3511 are nonsynchronous pulse stuffing multiplexers. It should be emphasized, however, that when the WAWS i used to carry synchronous data traffic for the DTN, at least the KG-81, AN/FCC-98, CY-104A, and LSTDM are required to operate synchronously. To accomplish this, the DCS station clock and distribution subsystem are required as shown in Figure 13. A station clock is provided for the KG-81 and the CY-104A transmit signals. The transmit clock signal is passed to the AN/FCC-98 and LSTDM as indicated. As indicated by the dashed lines, the node operates synchronously up to the CV-3511 input. Here, the same choice is not available as it was in the overseas digital transmission facilities where it was decided to synchronously operate the radio and second level multiplexer (AN/FCC-99). In the WAWS, the TD-1220/CV-3511 and DMX-A3 do not have a synchronous mode of operation with the required buffers. With respect to the DTN circuits, the transmitted signals from the synchronous part of the node are synchronous with the station clock. All received signals are synchronous with the transmitting node station clock. Data circuits that are dropped are done so without any further buffering. All data circuits that are through-routed in the synchronous portion of the node are buffered. All circuits (digroup and MBS) that are through-routed are pulse stuffed to compensate for clock differences and transmission delay variations.

(2) Commercial Leased Data Service. Figure 14 depicts two typical leased data services that potentially will be used in the DTN.

The AT&T Digital Data System (DDS) provides a private line, full duplex, point-to-point, and multipoint data service in and between 90 metropolitan areas. Transmission rates of 2.4, 4.8, 9.6, and 56 kb/s are provided as shown in Figure 14a. For interfacing the user to the DDS network, a customer service unit (CSU) is used, which provides an EIA RS 232C standard electrical interface. The RS 232C electrical interface has subsequently been redefined by EIA Standards RS 422 and RS 423 for balanced and unbalanced NRZ interfaces, respectively. These new commercial interfaces are compatible with MIL-STD-188-114. The DDS is a synchronous network slaved to a common clock located near Hillsboro, Missouri. User data terminals that are provided service by the DDS are slaved to the transmission network. The DTN and DDS are similar in that they use independent timing sources. The actual source clocks have equivalent characteristics in terms of accuracy and stability. Since they are independent sources, however, a small amount of buffering is required to compensate for clock differences to maintain BCI. For the case of low speed circuits multiplexed by the LSTDM, the buffering is provided by the LSTDM port modules. Where circuits interface directly at rates of 2.4, 4.8, 9.6, and 56 kb/s, the DCS data buffer will be used.

The DTN network may also provide digital circuits over leased satellite systems. In this application, the 1.544 Mb/s digroup is leased and the circuit is transmitted with a CY-104A, as shown in Figure 14b. There are currently 7 of these leases in operation and there are plans for ten more. The CY-104A interface with the commercial system is nonsynchronous and in most cases provided by a pulse stuffing, second level multiplexer. In the present configuration, these equipment arrangements do not require station clocks. Where these facilities are used to support DTN circuits, they will have to be equipped with or slaved to a station clock to provide an accurate transmit timing source. Further, they will be required to compensate for satellite delay variations, and the CY-104A may require an input buffer for those cases where the terminating equipment is not clocked by the CY-104A as discussed in the preceding section. As shown in Figure 14b, where the LSTDM is used and clocked by the CY-104A, the input buffering is provided by the LSTDM port module buffers.



a. DTN/DDS Leased Equipment Configuration

b. DTN/Wideband (Digroup) Leased Equipment Configuration

Figure 14. DTN Leased Digital Transmission Facilities

V. DIGITAL SIGNAL INTERFACE

The purpose of this section is to specify the specific digital, electrical, mechanical, control and signal quality interface characteristics for the DTN. Guidance for these parameters is provided by DoD Military Standard, Federal standards, commercial (Electronic Industries Association (EIA)) standards and CCITT recommendations. Over the past ten years, there has been considerable effort to revise and upgrade these standards, but there is considerable confusion in this area since the standards have been in a continual process of change. The digital transmission equipments being used to implement digital DCS transmission facilities have also been developed at different times over the past ten years, and therefore they have been designed to different commercial and military standards. For example, when the DRAMA (Digital Radio and Multiplex Acquisition) program evolved, the equipment used for the current digital upgrading of the DCS transmission facilities was developed to MIL-STD-188-100. Paragraphs V.2 and V.3 of MIL-STD-188-100 covering electrical interface characteristics have subsequently been replaced by MIL-STD-188-114. MIL-STD-188-100 does not cover mechanical interfaces, and control circuits and digital signal quality are covered only for specific cases (i.e., in VF modems, teletype, facsimile). Digital signal quality is not appropriately covered in any DoD standard for a worldwide synchronous digital network. Further, MIL-STD 188-114 does not address mechanical interfaces or specify digital signal quality parameters.

The Electronics Industry Association (EIA) standard RS 232 C, dated Aug 1969, covered electrical, controls, and mechanical interfaces. EIA standard RS 334 covered signal quality for clock interface signals. In the mid-70's, RS 232 C was superseded by RS 422 for balanced digital interface, RS 423 for unbalanced digital interface, and RS 449 for mechanical interface and control signals. RS 422 and RS 423 are almost equivalent to MIL-STD-188-114 in specifying the electrical characteristics for balanced and unbalanced circuits respectively. The exceptions are the magnitude of the voltage offset (VOS) for balanced interfaces and the circuit protection requirements. MIL-STD-188-114 limits VOS to .4 volts instead of the 3 volts allowed by RS 422. This restricted VOS provides the capability of interfacing flexibility for the equipment designed to MIL-STD-188-100 but imposes the requirement to have two power supply sources. Interface devices designed to operate in accordance with RS 422 can operate from a single power source. In addition there are two circuit protection requirements imposed by MIL-STD-188-114 that are not imposed by the commercial standards. The first requires the receiver to tolerate up to 12 volts (with a design objective of 25 volts) between receiver leads. The other requirement is protection against voltage transients of up to 1000 volts peak. The transient voltage requirement is for lighting protection and is similar to what would be required for HEMP protection. Neither of the two protection requirements have been fully imposed on recent transmission equipment procurements for various reasons. If standards impose requirements that are impossible, they should be changed, but interface standards, uniformly applied, are essential for implementing a digital network that provides specified levels of performance.

Federal Standards 1020, 1030 and 1031 adopt RS 422, 423, and 449 for Federal Government applications. The Federal Standards further stipulate that MIL-STD-188-114 must be used for the reasons cited above. Note that CCITT Recommendations X.26 for unbalanced interfaces and X.27 for balanced interfaces agree very closely to RS 423 and RS 422 respectively. CCITT Recommendation X.27 for balanced interface has exact parameters that exactly match RS 422 except that receiver sensitivity is specified at 300 mV as opposed to 200 mV. Figure 4.2 of RS 449 presents a list of interchange circuits showing the nearest equivalent to RS 232C and CCITT identification, in accordance with recommendation V.24. Notice, however, that the circuit definitions given in RS 449 should not be inferred to be in exact accord with RS 232C and the CCITT recommendations for current equipment developments. It is noted that RS 499 and FED-STD-1031 apply to data circuits over analog transmission facilities and therefore only apply to the DTN where VF and group data modems are used over analog facilities.

1. ELECTRICAL CHARACTERISTICS

Table X specifies the electrical characteristics for both NRZ and conditioned diphase signals. Except for the special cases where conditioned diphase will be used, all digital data and timing signals will meet all requirements of MIL-STD-188-114. Any exceptions will be made only on a case-by-case basis. Circuits designed to meet these parameters will be interfaced with circuits designed to MIL-STD-188-100, Commercial Standard RS 422 and 423, and CCITT recommendations X.10 and X.11. These standards do not specify a specific output impedance. The standards do state, however, that if a generator meets the specified requirements, the output impedance should be 100 ohms or less for balanced circuits and 50 ohms or less for unbalanced circuits. In the same sense, receiver input impedances are specified to be 4000 ohms or greater. The standard also allows terminating resistors at the receiver input. The value of the terminating impedance should match the characteristic impedance of the cable being used to minimize reflections and preserve the signal rise time. For equipment presently implemented, this impedance has been specified to be 78 or 124 ohms. To provide guidance in this matter it is recommended that any future equipment be designed to provide 124 $\pm$ 10% ohms terminating resistance.

The conditioned diphase electrical signal characteristics must be compatible with TRI-TAC developed equipment. DTN equipments that have conditioned diphase interfaces at 16 kb/s or 32 kb/s may have to interface directly with TRI-TAC switches (AN/TTC-39, SB3865, AN/TTC-42) TCCF, or the Loop Group Multiplexers (TD 1235) to extend tactical user circuits through the DCS. These TRI-TAC equipments have the capability of providing remote power to user terminals. If the power is inadvertently applied, the equipment being interfaced will be subjected to up to 55 volts between the transmit and receiver leads. Suitable protection must be provided to avoid possible equipment failure when used in this configuration.

2. MECHANICAL INTERFACE/CONTROLS

Currently there is no standard military mechanical connector for use with strategic communications equipment. Some equipments use connectors that meet the requirements for tactical applications and others use connectors that meet commercial standards. In general, the only specification that has been given for both signal and power connectors is that it be a quick disconnect type. Commercial connectors defined by RS 449 will be used for digital interfaces for VF and Group Modems as required by FED-STD-1031. In general, other digital interfaces require greater than the 9 pin connectors and much fewer than the 37 pin connectors. A synchronous port of the LSTDM, for example, requires 11 pins (4 pins for received and transmit data, 6 pins for receive and transmit clock, and 1 pin for ground). This mechanical interface can be satisfied with a 15 pin or a 25 pin connector. The standard, RS 232C, 25 pin connector is more available and therefore recommended for DTN applications.

3. DIGITAL SIGNAL QUALITY

Table XI defines digital signal quality specifications that will be met in the DTN. In a worldwide network, the digital signals may be required to traverse a multitude of interfaces at various levels of the digital hierarchy. For example, some circuits of the DTN will route through as many as seven LSTDM data trunks. A digital circuit that traverses seven data trunks relies on the proper operation of numerous digital interfaces. To guarantee a specified level of performance, each of these interfaces must be carefully controlled to minimize the effect of distance on user-to-user performance. This can be accomplished to the extent interface problems contribute to performance degradation if each transmission subsystem maintains the specified signal quality parameter given in Table XI. The NRZ signal quality parameters are consistent with MIL-STD-188-100 for low- to medium-speed synchronous interface, and with EIA STD RS 334.

The slew rate requirement is not covered in any current standard. Slew rate is best described as the rate of change of isochronous distortion. The principal source of this impairment is time division multiplexers that use pulse stuffing. The parameters specified in Table XI are based on the DRAMA equipment.

TABLE X. DTN DIGITAL SIGNAL ELECTRICAL CHARACTERISTICS

1. NRZ (MIL-STD-188-114 dated 24 March 76)

Balanced	Input	Output
1) Levels (volts (v))	$\pm$(.2 to 6.0 V)	$V_{oc} \leq \pm 6V_{oc}$ $2V \leq V_t \geq .5\ V_{oc}$ $R_t = 100$ ohms
2) Impedance (ohms)	>4k	≤100
3) Terminating Resistance (ohms)	124 ± 10%	
4) Rise and fall time (t_r)		≤ 10% of data period
5) Receiver protection		
1. Continuous (dc Volts): 12V (DO 25V)		
2. Transients: 1000 V, t_r = 5 ms, duration .6 ms, 350 V, t_r = 10 ms, duration .2 ms		
6) Signal sense: provisions to invert		
7) Short Circuit Current:		< 150 mA

Unbalanced	Input	Output
1) Level (volts)	± .2 to ± 6.0 volts	Voc = ± 4 to ± 6V V_t = .9 Voc R_t = 450 ohms
2) Impedance (ohms)	> 4k	≤ 50
3) Terminating Impedance (ohms)	124 ± 10%	
4) Output rise time; less than 1000 b/s 100 ms to 300 ms greater than 1000 b/s .1 to .3 of period		
5) Receiver protection		
1. Continuous (dc Volts): 12V (DO 25V)		
2. Transients: 1000 V, t_r = 5 ms, duration .6 ms, 350 V, t_r = 10 ms, duration .2 ms		
6) Signal sense: provisions to invert		
7) Short Circuit Current:		< 150 mA

2. CONDITIONED DIPHASE (TRI-TAC Spec #TT-A3-7005-0040 dated 8 July 77)

Balanced	Input	Output
1) Level	± (.075 to 7.0 volts)	3V p-p ± 10% R_t = 125 ohms
2) Impedance (ohms)	125 ± 10%	125 ± 10%
3) Receiver threshold	100 mV p-p	
4) Rise and fall time (10 to 90%)	100 ms ± .15 data period	
5) Protection: (Circuit must be protected from 55 Vdc DSVT Power Source)		
1) short circuit output current	≤ ± 40 mA max	

TABLE XI. DTN DIGITAL SIGNAL QUALITY

	Input (≤)	Output (≤)
1. NRZ (Balanced and Unbalanced)		
1. Peak-to-Peak Isochronous Distortion (%)	12.5	2
2. Peak Individual Distortion (%)	5	.5
3. Data/Timing Phasing (%)	25	4
4. Bias Distortion: (Asyn/Isoc ≤ 100 b/s)	30	
5. Slew Rate Rad/ # Pulses	$\pi/2500$	$\pi/5000$
6. Rate Accuracy (ppm)*	± 250	± 2
7. Clock Symmetry(%)	50 ± 25	50 ± 4

2. CONDITIONED DIPHASE

	INPUT (≤)	OUTPUT (≤)
1. Isochronous Distortion (%)	10	2
2. Rate Accuracy (ppm)		
a] Master operation (looped)	70	50
b] Acquisition	1900	3000

* New user and transmission equipment should be designed with internal clock accuracies at least as good as two part per million (ppm) but must be able to interface with older equipment that have rate accuracies of 250 ppm. It is noted, however, that earlier terminal devices (teletype) have rate sources whose accuracies are determined by primary power sources and electromechanical apparatus, and can be significantly worse than 250 ppm.

VI. NETWORK IMPLEMENTATION ENGINEERING CONSIDERATIONS

A systematic approach to the implementation of the data transmission network should be based on a network consisting of a coordinated set of LSTDM derived trunks. This systematic approach entails developing a requirements model, using the DCEC ROUTER (reference 15) to determine trunking configurations, developing an agreed-to objective configuration, and transitioning to that objective configuration.

Routing of the DTN trunks requires an examination of economic, survivability, and restorability considerations. Detailed circuit engineering and allocation processes must consider the user interfaces and performance (delay, BCI, error rate, etc.) requirements, if any, imposed by user systems.

1 NESTING

The FYP 83 DTN network design did not use the concept of "nesting" DTN data trunks by applying the aggregate channel of one LSTDM into a port of another LSTDM. The procedure that was followed was to multiplex up to 16 data circuits into a data trunk of 9.6 kb/s for analog channels or 56 kb/s for digital channels. If additional data circuits were required between the same two locations, additional data trunks were used regardless how inefficiently the first data trunk was loaded. The decision to "nest" should be a deliberate one made during the circuit allocation and engineering process. That decision must take into account performance, survivability, restorability, transmission aspects and other economic aspects. As an example, consider the case of the LSTDM data trunks between Andrews AFB and the Pentagon. FYP 83 showed a needline for three trunks between the two stations. A check of the requirements model showed that the three trunks could possibly be combined into one 56 kb/s data trunk by using three nested submultiplexers. The choices available then were using one, two, or three 56 kb/s channels between the two stations, depending upon the operational requirements. Using only one 56 kb/s data trunk would provide the most efficient utilization of the available transmission channels. Using two or three channels over diverse paths would provide alternate DTN trunks for restoration in event of failure of one trunk. Thus a sacrifice in efficiency would improve the restorability and the potential availability of the circuits.

2. CIRCUIT ENGINEERING

a. Interfaces. The user interface with the LSTDM will be those standard interfaces (synchronous, asynchronous, and isochronous) at the standard rates identified in section III. Particular attention must be paid to the clock configuration requirements of each user interface and the interface between tandemed data trunks.

b. Tandeming. A typical example of a tandemed data circuit would be a circuit between Frankfurt and Ramstein operating at a rate of 50 b/s. This circuit could traverse Frankfurt - Pirmasens and Pirmasens - Ramstein data

trunks. The LSTDM would handle this circuit by use of transitional encoding with a port line rate of 300 b/s. At the tandeming point (LSTDM to LSTDM), Pirmasens, synchronous port modules operating at 300 b/s must be used. The rate must "match" the line rate of the port used to interface the user. This is necessary to prevent the accumulation of excessive phase distortion. In any case, until testing has been accomplished, circuits of this type should not be planned for more than four tandem LSTDM trunks. The LSTDM specification places a distortion limit of only four tandem trunks.

c. Multipoint Circuits. It could be very easy to exceed the limit of four tandem trunks on multipoint circuits. Therefore, attention should be given to including a regenerative repeater function at hubbing points, where required.

d. Total Absolute Delay. The user equipment for which the DTN will provide transmission circuitry will sometimes have a specified time interval within which the distant terminal must send a reply to the near-end terminal. Each piece of digital equipment in the path (e.g., multiplexer and repeater) adds absolute delay to the transmission of the data stream. Again, looking at the circuit between Frankfurt and Ramstein, but assuming it operates at 75 b/s, the circuit traverses two LSTDM trunks, each of which is carried over two LOS links. Based on the current LSTDM design, the data trunk delay would be between .5 and 1 second. If the user terminal equipment looks for a response in less than this period, then its allowable time delay limit would be exceeded. In this case, the user response time limit would have to be increased or a differently engineered circuit provided, if possible, to satisfy the time limit. As DTN data trunks are installed, the absolute delay over the trunks should be determined and recorded for use by circuit engineers when the user specifies a "round trip delay" limit.

3. RESTORABILITY

As pointed out in paragraph VI.1, diverse routing between locations served by two or more LSTDM trunks improves the restorability of individual circuits. Therefore, diverse routing should be considered during channel allocation for LSTDM trunks. Another method of restoration, on a trunk basis, would require preplanning with prepositioning of channel cards and other ancillary equipment.

If it is decided that "restoral paths" for the DTN trunks should be pre-engineered with any necessary equipment prepositioned at intervening stations, then standard or common rates should be adhered to. For example, if it is decided that a pre-engineered restoral path between Croughton and Hillingdon via a different path is required for a DTN trunk, then as a minimum, prepositioning an AN/FCC-98 data channel card for the restoral path would be required at both stations. At any intervening stations where temporary patchs would be made, prepositioning of the data cards would also be required.

4. TRANSITIONAL CONSIDERATIONS

As with any program, implementation of the DTN requires coordination with other programs during the transition from today's system. Some of these programs are the Network Timing and Synchronization Project, Technical Control Improvement Project, Terrestrial Transmission Digitization Projects (e.g., DEB, HAWS, WAW V) and the DSCS. Additionally, coordination of procurement of modems, line drivers, TRAMCON units and other support items will be required within the basic DTN project.

The FYP 83 proposed DTN trunking was developed using a DCS circuit file circa March 1979 and other requirements papers of that same vintage. Assumptions used and modifications to the model were as identified in FYP 83. The DCEC Router Program was used to develop "link fills" which were turned into "trunk fills". These reports were then used as the basis for the trunk listings (except for the DSCS) that appeared in FYP 83. The DSCS listings were a "given" from the DSCS program.

Since the FYP 83 DTN trunks were developed for planning and programming purposes and modified in the FYP-84 and FYP-85 process, review of the trunks and the requirements upon which they are based is necessary. Therefore, a requirements verification/validation effort appears to be necessary. The quickest way of doing this would be to do a manual comparison of today's requirements with the model used for FYP 83. However, there are two other ways of achieving the same goal without verifying the accuracy of the FYP 83 requirements model. One way would be to take the new requirements model and do a channel allocation, or circuit loading, job on the FYP 83 trunks (as modified in FYP 84 and FYP 85). This would tend to verify and modify the FYP design without the intermediate step of verifying the FYP 83 requirements model. Another way would be to use this new requirements model along with the ROUTER program to update the DTN configuration. Regardless of which way is chosen, an agreement on the DTN objective configuration is necessary prior to starting hardware implementation.

After a network configuration agreement is achieved, the major question of how to transition to it must be faced. FYP 83 indicates in broad terms that "as the transition of the DCS transmission system from frequency division multiplex to time division multiplex progresses, digital submultiplex equipment would be introduced to accommodate teletype and medium speed data users. Additionally, digital submultiplexers with modems would be used in those areas which will remain analog for the foreseeable future." DCEC TR 3-74, "Digital Transmission System Design" (reference 16), which used the Feldberg-Augsberg-Coltano (FAC) project (later incorporated into the DEB) as a model, used the following assumptions and selection principles for determining how to transition to digital submultiplexing:

- o Data and teletype requirements which originate and terminate with the FAC would be considered for submultiplexing.

- VFCT's which do not originate or terminate within the FAC, but traverse the FAC facilities for long distances, would be considered for breakdown and digital submultiplexing for transmission through the FAC. As an exception, a VFCT between two stations carrying only point-to-point circuits between those two stations would be considered for retention.

- VFCT's which either originate or terminate at FAC stations and traverse FAC facilities would be considered for breakdown and submultiplexing.

- Existing "speech plus data" circuits would remain in their present configuration.

- Leased data and teletype services between two FAC stations would be considered for digital submultiplexing.

In general, the principles espoused above should still be applicable. After obtaining an agreement on the objective system configuration, the following transition steps could apply for implementing the trunks of the objective system:

- Implement those trunks which can be wholly supported by digital transmission.

- Implement those trunks for which the final design is to be supported partially or wholly by analog systems.

- As the remainder of the system becomes digital, the DTN trunks supported by those upgrades can be implemented.

- Interim installations should be considered to temporarily relieve space shortages or to facilitate other cutovers.

In short, the early implementations could come where digital systems exist or analog systems will remain for the foreseeable future. Other implementations could be accomplished as digital systems are implemented.

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LIST OF ACRONYMS

AM	Adaptive Multiplexer
BCI	Bit Count Integrity
BEC	Burst Error Coder
BER	Bit Error Rate
CAWS	California Area Wideband System
CCSD	Command Communications Service Designator
CD	Conditioned Diphase
CSU*	Customer Service Units
DCE	Data Circuit-Terminating Equipment
DCEC	Defense Communications Engineering Center
DDN	Defense Data Network
DDS*	Digital Data System
DDU	Digital Distribution Unit
DO	Design Objective
DRAMA	Digital Radio and Multiplexer Acquisition
DSCS	Defense Satellite Communications System
DSN	Defense Switched Network
DSVT	Digital Subscriber Voice Terminal
DTE	Data Terminal Equipment
DTN	Data Transmission Network
DTNCC	Data Transmission Network Control Centers
ECCM	Electronic Counter-Countermeasures
ECWIS	East Coast Wideband Integrated System
ET	Earth Terminal
ETS	European Telephone System
FAC	Feldberg-Augsburg-Coltano
FASR	Fault Alarm Status Reporting
FIFO	First-in-first-out
FDM	Frequency Division Multiplexer
FYP	Five Year Program
GDM	Group Data Modem
HAWS	Hawaii Area Wideband System
HNA	Host National Approval
ICF	Interconnecting Facilities
IST	Interswitch Trunk
JCS	Joint Chief of Staff
LC	Looped Clock
LD	Line Driver
LSTDM	Low Speed Time Division Multiplex
MBS	Mission Bit Stream
MSO	Military Satellite Office
NRZ	Non-Return-to-Zero
PPS	Parts per million
PSTN	Public Switched Telephone Network
PTT	Post Office Telephone and Telegraph
RF	Radio Frequency
RTACS	Real Time Adaptive Control System
TCCF	Tactical Communications Control Facility
TCF	Technical Control Facilities
TCN	Telecommunications Network

TDM	Time Division Multiplexer
UART	Universal Asynchronous Receiver Transmitter
UTC	Coordinated Universal Time
VF	Voice Frequency
VFCT	Voice Frequency Carrier Telegraph
VOS	Voltage Offset
WAWS	Washington Area Wideband System

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